International Geology Review

Vol 2, No. 4 April 1960

PARTIAL CONTENTS

- complete table of contents inside -

published by the
AMERICAN GEOLOGICAL INSTITUTE

The American Geological Institute operates under the National Academy of Sciences. It is governed by an Executive Committee and a Board of Directors composed of two directors from each of the fourteen Member Societies.

International Geology Review is published monthly by the American Geological Institute with the assistance of an initiating grant from the National Science Foundation. The journal will report, in English, significant contributions to pure and applied research in the earth sciences which appear in foreign-language journals, especially those published in the U.S.S.R.

The editors of International Geology Review will give consideration to full English translations, condensations, and reviews submitted voluntarily for publication. Translators will be appropriately credited.

Readers are invited to direct to the editors their comments and discussions of articles published in the International Geology Review. Readers are encouraged also to submit suggestions as to published foreign literature considered worthy of translation and publication. Such suggestions should relate to materials of broad, general interest, rather than materials of limited reader interest.

Address editorial and subscription inquiries to

AGI TRANSLATIONS OFFICE
AMERICAN GEOLOGICAL INSTITUTE
2101 Constitution Avenue, N.W., Washington 25, D. C.

The basic subscription rate for International Geology Review is $55 per year, 12 issues. A special subscription rate of $15 per year is available to members of AGI Member Societies who are on the GEOTIMES mailing list and who will pledge to restrict the journal to their personal use. The $15 per year subscription rate is also available to educational institutions and personnel. Foreign postage: No additional charge to Canada and Mexico; to Pan American Union countries add $0.50 per year; to all other foreign countries add $1.00 per year. Single copy price $5.00 ($1.50 to subscribers qualifying for special rates). Second class postage paid at Washington, D. C.

International Geology Review

published monthly by the
AMERICAN GEOLOGICAL INSTITUTE

Vol. 2, No. 4. April 1960

Page

CONTENTS

REVIEW SECTION

IGR TRANSLITERATION OF RUSSIAN

The AGI Translation Office has adopted the essential features of Cyrillic transliteration recommended by the U. S Department of the Interior Board of Geographic Names, Washington D. C.

Alphabet		transliteration
А	а	a
Б	б	b
В	в	v
Г	г	g
Д	д	d
Е	е	e, ye (1)
Ё	ё	ë, yë
Ж	ж	zh
З	з	z
И	и	i (2)
Й	й	y
К	к	k
Л	л	l
М	м	m
Н	н	n
О	о	o
П	п	p
Р	р	r
С	с	s
Т	т	t
У	у	u
Ф	ф	f
Х	х	kh
Ц	ц	ts
Ч	ч	ch
Ш	ш	sh
Щ	щ	shch
Ъ	ъ	" (3)
Ы	ы	y
Ь	ь	' (3)
Э	э	e
Ю	ю	yu
Я	я	ya

However, the AGI Translation Office recommends the following modifications:

1. Ye initially, after vowels, and after ъ, ь. Customary usage calls for "ie" in many names, e. g., SOVIET KIEV, DNIEPER, etc.; or "ye", e. g., BYELORUSSIA, where "e" follows consonants. "e" with dieresis in Russian should be given as "yo".
2. Omitted if preceding a "y", for example, Arkhangelsky (not "iy"; not "ii").
3. Generally omitted.

NOTE: Well-known place and personal names that have wide acceptance will be used. Some translations may include elements of previous German transliteration from the Russian; this occurs in IGR most commonly in maps and lists of references. The reader's attention is called to the following variations between German and English systems which may cause confusion when trying to check back to original Russian sources.

German	English
w	v
s	z
ch	kh
tz	ts
tsch	ch
sch	sh
schtsch	shch
ja	ya
ju	yu

TENTATIVE CONTENTS FOR THE MAY ISSUE

PETROCHEMICAL STUDY OF THE CENOZOIC BASALTIC ROCKS IN EASTERN CHINA (PART 2 OF 2)[1]

by

Chao Tsung-pu[2]

• *translated by E. C. T. Chao* •

THE STUDY OF THE ROCK SERIES

Classification of the Chemical Types

In the Cenozoic epoch, basalts were extruded in large areas of eastern China, and in the Pai-t'ou-shan area of Kirin the extrusion of basalt was followed by more acidic trachyte and alkalic lavas. In order to study the volcanic rocks of eastern China systematically, and to compare them with volcanic rocks of other parts of the world, basalts, trachytes and alkalic lavas can be classified into various types of the basis of the silica content. According to Table 1, on the basis of silica content, the basalts of eastern China can be divided into five types:

1) Limburgite and basanitoid type, SiO_2 < 44 percent
2) Olivine basalt and trachybasalt type, SiO_2 44 - 49 percent
3) Tholeiitic basalt and leucite basalt type, SiO_2 49 - 55 percent
4) Alkali trachyte type, SiO_2 65 - 70 percent
5) Alkali rhyolite type, SiO_2 > 70 percent

The average chemical composition of each of these types is shown in Table 5A. This table contains the average of 71 basalts which are grouped into 3 types, and the average of 3 trachytes as one type, and the average of 4 alkali lavas as one type.

The basalts of Kuan-yin-shan of Taiwan are treated separately because the olivine basalt and the two pyroxene andesites clearly show non-alkalic characteristics. According to the SiO_2 content they are divided into three types.

1) Olivine basalt, SiO_2 < 50 percent
2) Pyroxene andesite, SiO_2 50 - 60 percent
3) Hornblende andesite, SiO_2 > 60 percent

The average chemical composition of each type is shown in Table 5B.

Comparison with Various Volcanic Series of Japan

Geographically the basalts of eastern China adjoin those of Korea and Japan, but petrographically they are similar to those of New Zealand. For purposes of comparison, the average compositions of the volcanic rocks of Japan and the Cenozoic alkali rocks of the Circum-Japan Sea region (areas bordering the Sea of Japan) are shown in Tables 6A and 6B.

Comparison with the Alkali Series of the Circum-Japan Sea Region

Tomita [15] (1932), in his study of the Cenozoic basalts of the Circum-Japan Sea region, considered the area northwest of a line from Oita and Kumamoto of Kyushu, Japan southwestward to the northeastern part of Taiwan, and continued to the Pescadores Islands and South China Sea, to be the Cenozoic alkali petrographic province of East Asia. Only various types of pyroxene andesites of the calc-alkali series of post-Pleistocene age appear to the southeast of this line. As mentioned before the basalts, trachytes and alkali lavas clearly belong to an alkali suite. For comparison, the variation diagram of the Cenozoic basalts of eastern China and those of the alkali suite of the Circum-Japan Sea region are shown in Figure 9.

The oxides are shown as the ordinate and SiO_2 percent as the abscissa. The basalts of eastern China are relatively low in Al_2O_3 and CaO but high in Na_2O, K_2O, and MgO. Fe_2O_3 and FeO fluctuate with FeO increasing and Fe_2O_3 decreasing as SiO_2 increases.[3] There is no comparison for intermediate rocks between these two regions because such rocks are missing in eastern China. For acid rocks, the Al_2O_3 content for Chinese volcanic rocks is still lower, and the Na_2O is still higher than those of the Circum-Japan Sea Region but K_2O has become less than those of the latter area; whereas CaO and MgO tend to be nearly the same. Both FeO and Fe_2O_3 as well as TiO_2 and P_2O_5 are higher in rocks of eastern China

---

[1] Translated from Chung Kuo Tung Pu Hsin Sheng Tai Shuan Wu Yen Lai Yen Shih Hua Hsueh Ti Yen Chiu: Acta Geologica Sinica (Ti Chih Hsueh Pao) v. 36, no. 3, p. 315 -367, 1956. In transliterating place names, the Wade-Giles system is used. Part 1, including a complete abstract of this work, appeared in the International Geology Review, v. 2, no. 3, March 1960.
[2] Institute of Geology, Academia Sinica

[3] Reviewer's Note: The author has plotted the Fe_2O_3 value of analysis D (Table 5A) incorrectly on Figure 9. Were it correctly plotted the author should have said "FeO decreased with increase of silica content, whereas, in the same direction, Fe_2O_3 increases at first, then decreases." -- C.O.H.

TABLE 5A. The average chemical composition of the Cenozoic volcanic rocks of eastern China

Rock type		A	B	C	D	E
SiO₂%		$SiO_2<44\%$	$44\%<SiO_2<49\%$	$49\%<SiO_2<55\%$	$55\%<SiO_2<70\%$	$SiO_2>70\%$
Composition		12 samples	38 samples	21 samples	3 samples	4 samples
SiO_2		42.68	46.90	51.68	66.98	72.13
Al_2O_3		13.53	14.99	15.18	14.34	10.66
Fe_2O_3		4.35	4.99	4.53	1.63	2.80
FeO		8.24	6.73	5.52	3.06	3.20
MgO		8.88	7.36	5.24	0.17	0.09
CaO		9.83	8.72	7.36	1.39	0.58
Na_2O		4.02	3.42	3.70	6.13	5.11
K_2O		2.06	2.08	3.28	4.99	4.39
TiO_2		2.46	2.18	2.08	0.56	0.34
P_2O_5		0.82	0.64	0.65	0.13	0.12
MnO_2		0.10	0.15	0.10	0.12	0.11
H_2O		2.93	2.19	1.23	0.43	0.90
Q		-17.46	-7.26	-2.21	10.32	26.70
Or		12.23	12.23	19.46	29.47	36.13
Ab		6.81	22.53	31.44	45.59	30.39
An		12.51	19.46	15.02	...	...
Ac		...	...	...	4.62	7.87
Ne		14.77	3.41	...	...	...
Di		24.93	16.15	14.39	5.39	1.70
Hy		...	...	1.56	2.32	4.62
Ns		...	...	...	0.12	0.85
Ol		12.71	11.02	5.53	...	...
Mt		6.26	7.19	6.50	...	...
Il		4.71	4.26	3.95	1.07	0.61
Ap		2.02	1.34	1.34	1.00	0.34
Wt%	Or	38.5	22.5	29.5	39.2	46.2
	Ab	21.6(35.3)	41.5(53.5)	47.7(67.6)	60.8(100)	53.8(100)
	An	39.6(64.7)	36.0(46.5)	22.8(32.4)	...	...
Wt%	Wo	52.1	52.4	47.2	48.8	47.6
	En	35.7	37.8	42.0	3.7	6.0
	Fs	12.2	9.8	10.8	47.5	46.4

Note: A - Limburgite - basanitoid type. B - Olivine basalt - trachybasalt type. C - Tholeiitic basalt - leucite basalt type. D - Alkali trachyte type. E - Alkali rhyolite type.

TABLE 5B. The average chemical composition of the volcanic rocks of Kuan-yin-shan of Taiwan

Composition \ Rock type	a	b	c
SiO_2	50.14	55.82	61.33
Al_2O_3	18.76	21.22	20.10
Fe_2O_3	2.34	1.92	1.92
FeO	6.20	2.89	2.17
MgO	7.29	4.15	2.95
CaO	9.60	6.49	4.78
Na_2O	2.44	3.62	3.85
K_2O	1.70	1.87	1.69
TiO_2	0.90	0.45	0.37
P_2O_5	...	...	...
MnO	0.09	0.10	0.04
H_2^+O	0.87	1.42	1.01
Q	...	6.18	16.9
Or	10.00	11.12	10.01
Ab	20.43	30.39	32.49
An	35.30	32.25	23.91
Di	9.85	...	...
Hy	11.13	15.45	9.87
Ol	7.52	...	...
C	...	1.43	3.16
Mt	3.25	2.78	2.78
Il	1.67	0·76	0.61
Ap	...	...	...
Wt% Or	16	15	15
Wt% Ab	30(36.5)	41(48)	49(58)
Wt% An	54(63.5)	44(52)	36(42)
Wt% Wo	24	...	...
Wt% En	23	85	86
Wt% Fs	53	15	14

Note: a - Olivine basalt type. b- Two-pyroxene andesite type. c - Hornblende andesite type.

TABLE 6A. The average composition of the Cenozoic alkali volcano rocks of the Circum-Japan Sea Pegion

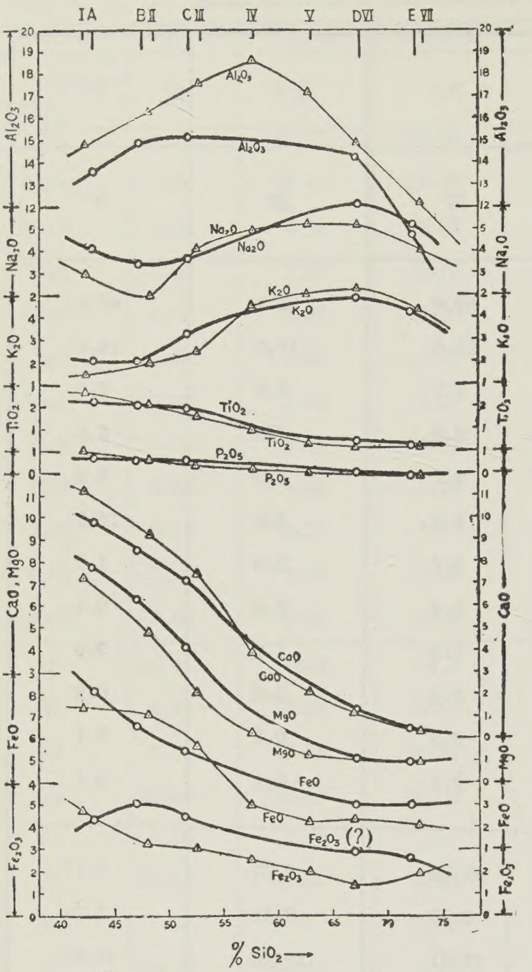
Rock type / No. of analyses / Composition	I	II	III	IV	V	VI	VII
	12	27	14	11	16	16	21
SiO_2	41.97	47.77	52.35	57.51	62.63	66.97	72.71
Al_2O_3	14.94	16.41	17.67	18.71	17.25	14.93	12.14
Fe_2O_3	4.73	3.29	3.17	2.63	2.13	1.55	2.12
FeO	7.56	7.20	5.75	3.18	2.34	2.44	2.26
MgO	8.43	5.94	3.16	1.38	0.40	0.27	0.16
CaO	11.34	9.34	7.61	4.00	2.21	1.28	0.62
Na_2O	3.02	3.44	4.24	5.02	5.34	5.30	4.26
K_2O	1.50	2.08	2.54	4.65	5.19	5.47	4.49
H_2O	2.83	1.45	1.14	1.18	1.55	1.12	0.84
TiO_2	2.70	2.19	1.71	1.11	0.55	0.43	0.28
P_2O_5	1.10	0.69	0.48	0.40	0.20	0.09	0.04
MnO	0.48	0.20	0.18	0.15	0.21	0.15	0.09
Q	-12.9	-6.3	-1.2	0.48	6.48	12.42	28.62
Or	8.90	12.23	15.01	27.80	30.58	32.25	26.69
Ab	8.91	24.10	36.63	42.44	45.06	44.54	36.15
An	22.52	23.55	21.96	14.73	8.06	0.83	0.56
Ne	9.09	2.56	...	...	...	...	...
Di	21.16	14.84	9.98	1.83	1.64	4.09	2.16
Hy	...	...	4.12	4.72	2.15	1.36	1.39
Ol	13.40	10.85	3.25	...	...	...	...
Mt	6.50	4.87	4.64	3.71	3.02	2.32	3.02
Il	3.95	4.10	3.19	2.13	1.06	0.76	0.61
Ap	2.69	1.68	1.34	1.01	0.34	0.34	...
Wt% Or	22	20	21	33	37	41	42
Wt% Ab	22(28)	41(52)	49(62)	50(75)	53(85)	57(98)	57(98.5)
Wt% An	56(72)	39(48)	30(38)	17(25)	10(15)	2(2)	1(1.5)
Wt% Wo	52	52	36	14	21	37	29
Wt% En	35	32	38	54	27	13	11
Wt% Fs	13	16	26	32	52	50	60

Note: Based on Tomita [45](1935), I. Limburgite-basanite type (SiO_2 < 45 percent), II. Basalt-trachybasalt type (45 percent < SiO_2 < 50 percent), III. Trachyandesite-basalt type (50 percent < SiO_2 < 55 percent), IV. Trachyandesite type (55 percent < SiO_2 < 60 percent), V. Trachyte type (60 percent < SiO_2 < 65 percent), VI. Trachyrhyolite type (65 percent < SiO_2 > 70 percent), VII. Weakly alkalic rhyolite type (SiO_2 < 70 percent).

TABLE 6B. The average composition of the volcanic rocks of Japan

Rock type	1	2	3	4	5
Number of analyses / Composition	10	40	57	22	7
SiO_2	73.4	64.6	59.8	52.1	47.4
Al_2O_3	13.9	16.3	17.6	18.3	18.6
Fl_2O_3	1.4	2.6	3.7	3.9	6.6
FeO	1.0	3.1	3.8	7.0	5.5
MgO	0.5	1.6	2.7	4.5	5.3
CaO	1.6	5.3	6.9	9.8	12.2
Na_2O	3.0	2.9	2.7	2.2	1.8
K_2O	3.2	1.7	1.4	0.6	0.4
H_2O	1.5	1.3	1.2	1.2	2.0
TiO_2	0.1	0.3	0.2	0.5	0.2
P_2O_5	0.2	0.2	0.2	0.1	0.1
MnO	0.1	0.1	0.1	0.1	0.1
Q	39.62	26.16	19.48	9.75	7.17
Or	18.13	10.10	8.38	3.31	2.16
Ab	27.99	25.05	22.81	18.32	14.87
An	7.37	26.66	32.11	38.03	40.5
C	...	...	...	...	...
Di	...	0.47	2.06	7.66	13.95
Hy	2.17	7.00	9.17	15.85	11.74
Mt	1.66	3.75	5.36	5.53	9.23
Il	0.21	0.61	0.31	0.35	0.23
Ap	0.15	0.21	0.21	0.20	0.20
Wt% Or	37	17	13	6	4
Wt% Ab	49	41	37	31	26
Wt% An	54	42	50	63	70

NOTE: Based on Yamada 62 (1930), 1. Rhyolite type SiO_2 >70 percent, 2. Rhyolite-andesite type (70 percent > SiO_2 > 60 percent), 3. Andesite type (60 percent > SiO_2 > 55 percent) 4. Andesite-basalt type (55 percent > SiO_2 > 50 percent, 5. Basalt type (SiO_2 < 50 percent).



[Tr: Questioned point too high]

FIGURE 9. Variation diagram of the Cenozoic volcanic rocks of eastern China
—o— Volcanic rocks of eastern China (basalts and trachytes)
—▽— Alkali suite of the Circum-Japan Sea region

than those of the Circum-Japan Sea.[4] Chemically, the higher the Na_2O and K_2O accompanied by low Al_2O_3 and CaO the more alkalic the rock would be. From this variation diagram the volcanic rocks of eastern China are, therefore, more alkalic than those of the alkali suite of the Circum-Japan Sea region.

Comparison of the Alkali-lime Index

Peacock [63] in 1931 defined the alkali-lime index as the value of the SiO_2 content where the CaO and the Na_2O/K_2O curve intersect on the variation diagram. Figure 10 shows the alkali-

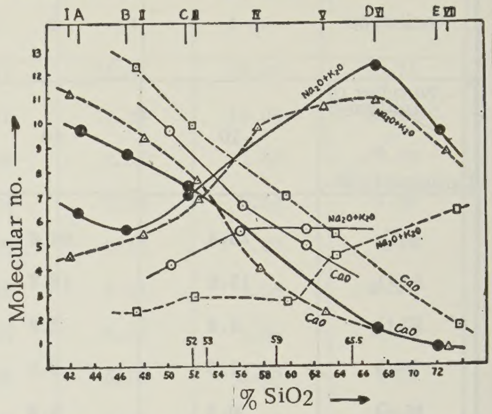


FIGURE 10. Alkali-lime index of the Cenozoic volcanic rocks of eastern China
—●— eastern China
—○— Kuan-yin-shan of Taiwan
—△— Circum-Japan Sea region
—□— Japan

lime index of the volcanic rocks of eastern China, those of rocks of the Circum-Japan Sea region are also shown for purpose of comparison. The alkali-lime index of the volcanic rocks of Japan is 65. 5, which belongs to the calcic category of Peacock; 58. 3 for Kuan-yin-shan of Taiwan which is calc-alkalic;53. 0 for the Circum-Japan Sea area and 52. 0 for eastern China, both alkali-calcic. This also shows the geographic variation of the Cenozoic volcanic rocks between the Japanese Archipelago and eastern China in East Asia. The alkali-lime index of the outer volcanic belt of Japan is 65. 5 (Nasu volcanic belt [64]) decreased to 60. 0 for the inner volcanic belt of Japan (Chokai volcanic belt [65]). The alkalic characteristics become more pronounced for volcanic rocks of Taiwan, the Circum-Japan Sea region and northern Korea. The alkali-lime index of volcanic rocks of the eastern part of the Chinese mainland diminished to 52. 0, which is more alkalic than those of the Circum-Japan Sea region.

Comparison of the Alkali-alumina Index

Holmes [66] in 1920 pointed out that in the variation diagram the Al_2O_3 curve and the Na_2O/K_2O curve delineate a different area between alkalic and non-alkalic rocks. Furthermore, for alkalic rocks, the Na_2O/K_2O curve and the Al_2O_3 curve intersect in high silica region, so that whether a suite is alkalic or not, or whether one suite is more alkalic than the other suite can be compared. Figure 11 shows the variation of the alkali-alumina index. The alkali-alumina index of the volcanic rocks of eastern China is 63. 3 and 67. 8, for those of the Circum-Japan Sea region it is 72. 2. Because of the lower alkali-alumina index, the volcanic rocks of eastern China are more

[4] Reviewer's Note: The author's statement so far as TiO_2 and P_2O_5 in basalts of each China and those of Circum-Japan Sea is not true in every case; compare Tables 5A and 6A. - - C.O.H.

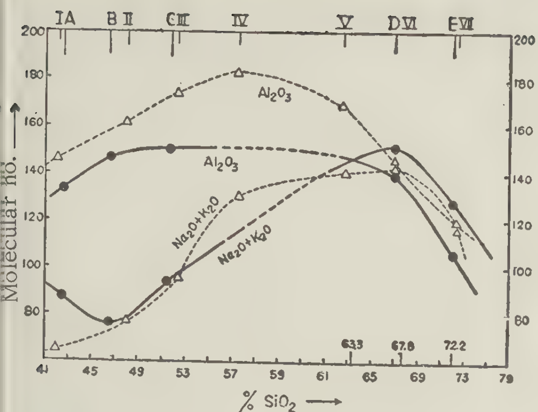


FIGURE 11. The alkali-alumina index of the Cenozoic volcanic rocks of eastern China
—●— eastern China
···△··· Circum-Japan Sea region

alkalic than those of the Circum-Japan Sea region.

Comparison of Normative Mineral Composition

On the basis of normative mineral composition of eastern China, Taiwan, Circum-Japan Sea region, and Japan shown in Tables 5A, 5B, 6A and 6B, every region has its individual petrochemical characteristics. Normative nepheline is present in the basalts of eastern China and the Circum-Japan Sea region, indicating their [high] alkalic and silica-poor characteristics. Such is not the case for Taiwan and Japan. The basalts of Taiwan contain normative corundum (C) indicating high Al_2O_3 and poor alkali content. Normative corundum occurs only in the rhyolitic rocks of Japan. It does not appear in the volcanic rocks of the Circum-Japan Sea region. Normative acmite (ac) appears in the rhyolites of eastern China where normative anorthite (an) is absent, and normative wollastonite (wo) is only present in residual amounts.[5] Normative an of the acid volcanic rocks of the Circum-Japan region is less than 1 percent, with appreciable amounts of wo, and those of Japan contain greater amounts of an (< 10 percent) but no wo. This indicates that the volcanic rocks of eastern China are rich in alkalies and poor in Al_2O_3 and CaO, whereas those of Japan are rich in Al_2O_3 and CaO, but poor in alkalies. The rest of the normative minerals of these volcanic rocks vary both in amounts and the stages of appearance.

The Variation of Olivine-quartz: The variation and amount of normative olivine and quartz of an igneous rock with respective to differentiation are indicative of the degree of silica saturation and whether it is weakly or strongly alkalic. With an-ab as abscissa, and the normative olivine and quartz as ordinate (quartz above and olivine below zero) the variation of the normative olivine-quartz based on table 5A with respect to the plagioclase composition can be shown as in Figure 12. For comparison, those

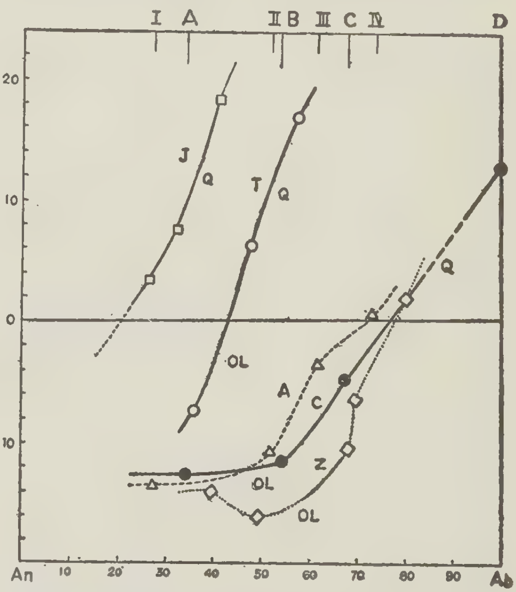


FIGURE 12. Comparison of the olivine-quartz index

C—●—Volcanic rocks of eastern China
T—○—Volcanic rocks of Kuan-yin-shan of Taiwan
A—△—Alkalic rocks of the Circum-Japan Sea region
J—□—Volcanic rocks of Japan
Z—◇—Volcanic rocks of east Otago, New Zealand

those of Japan, Circum-Japan Sea region, and New Zealand are also shown on the same diagram. The olivine-quartz index, which is the plagioclase composition corresponding to the zero value of normative olivine or quartz of the rock series, is 20.0 for the volcanic rocks of Japan, 43.0 for that of Kuan-yin-shan of Taiwan, 72.5 for that of the Circum-Japan Sea region, 76.5 for eastern China and 78.0 for New Zealand. This shows a gradual retardation of the transition of the crystallization of olivine to quartz. In other words, the stage of saturation of various rock series with respect to silica differs in time and should be directly related to the silica content and the total alkalies of the series. The diagram shows that the olivine-quartz index increases in the order: Japan, Kuan-yin-shan of Taiwan, the Circum-

[5] Translator's Note: Remarks on wo contradicts figures given in Table 5A which shows small amounts of en rather than wo, but quick inspection shows that the table is in error. Under column D and E, wo should be high in D and low in E and fs should be low in D and high in E.

Japan Sea region, eastern China, which means the lengthening of the period of crystallization of olivine as a result of the enrichment of alkalies and that the point of saturation with respect to silica has been delayed.

The Variation of Normative Nepheline-hypersthene: The appearance of normative nepheline is not only an indicator of undersaturation but also related to the content of alkalies. This is because normative nepheline and normative hypersthene are related by their non-compatibility. Figure 13, which shows the variation of normative nepheline and normative

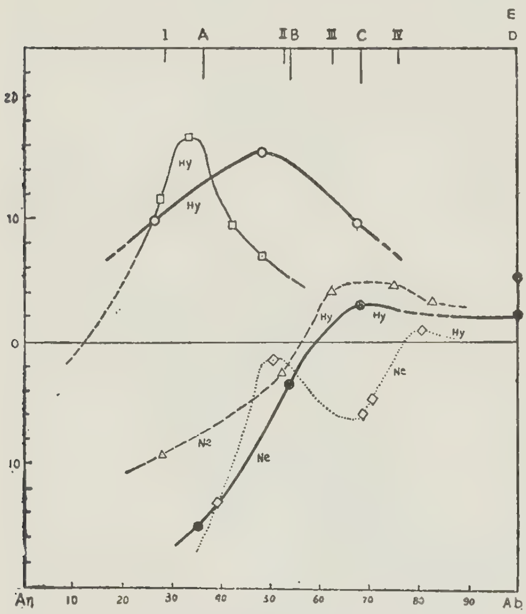


FIGURE 13. Comparison of the nepheline-hypersthene index (symbols same as in Figure 12)

hypersthene, is constructed in the same way as Figure 12. The nepheline-hypersthene index is the value of the composition of the plagioclase where the normative nepheline-hypersthene of the rock series is zero. From this diagram, there is no normative nepheline in the volcanic rocks of Japan and of Kuan-yin-shan of Taiwan. The nepheline-hypersthene index is 55.0 for rocks of the Circum-Japan Sea region and 59.0 for those of eastern China. This also means that the period of crystallization of nepheline of these series is retarded or extended, as a result of increasingly more alkalic as well as being more undersaturated in composition.

The Variation of Normative Corundum-diopside: Since the amount of normative corundun and diopside depends on how much an and wo have been used up and how much Al_2O_3 was left over, the alkalic content would effect the transition point of the appearance of normative corundum and diopside. The variation diagram of the normative corundum and diopside was constructed in a similar way as before and is shown in Figure 14. The corundum-diopside index is the

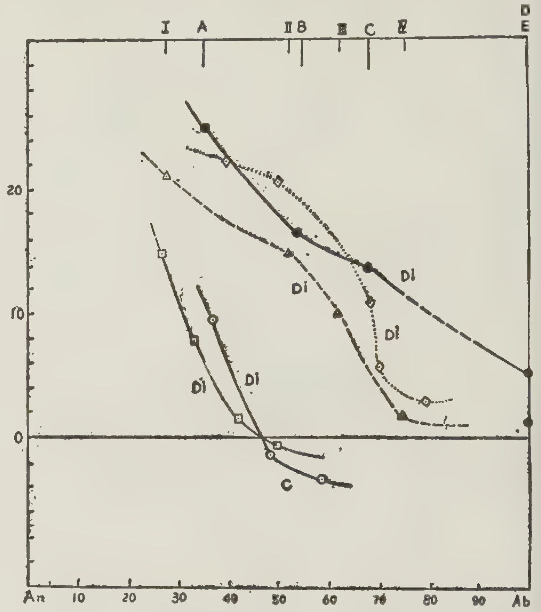


FIGURE 14. Comparison of the corundum-diopside index (symbols same as in Figure 12)

value of the composition of the plagioclase where normative corundum and diopside of the rock series are zero. Thus the corundum-diopside of the volcanic rock series of Japan and Kuan-yin-shan of Taiwan is 46.5. Normative corundum is absent from the series of the Circum-Japan Sea region, New Zealand and eastern China and departs farther above the zero line in this same order. It can be seen that from Japan, Kuan-yin-shan of Taiwan to the Circum-Japan Sea region to eastern China, the CaO content decreases gradually accompanied by the increase of the alkalies so that more Al_2O_3 is used up, raising the zero point of the series. This is another indication that the volcanic rocks of eastern China are high in alkalies and low in alumina.

The Variation of the Normative Feldspar Composition: Figure 15 shows the variation of the normative feldspar composition of the volcanic rocks of eastern China (in weight percent) including those of the Circum-Japan Sea region, Japan, and New Zealand. From this diagram, the volcanic rocks of eastern China have the highest or content, especially with regard to the more basic types (A, B, C). The or content increases from Japan, to Taiwan, towards the Circum-Japan Sea region and eastern China. The normative or content of the basalts and trachytes of New Zealand is similar to those of eastern China but the amount of or does not exceed that of eastern China. The figure

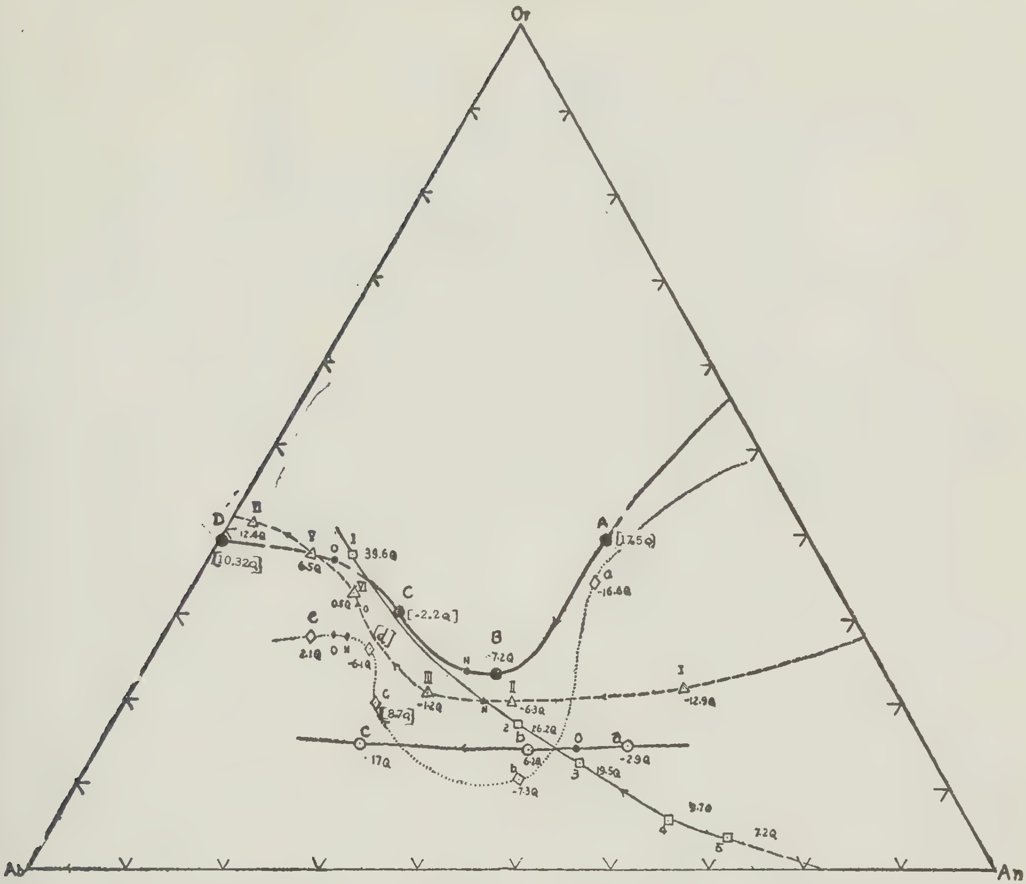


FIGURE 15. The variation diagram of the normative feldspar composition of the Cenozoic volcanic rocks of eastern China (in weight percent) (symbols same as in Figure 12) Data in brackets are revisions by Translator.

accompanying the letter Q next to the points in the diagram gives the normative Q value. A negative Q value is calculated by converting normative nepheline and olivine into sodic plagioclase and hypersthene. Points marked N and O correspond to the zero transition point of normative nepheline to hypersthene, and olivine to quartz respectively, of each series. In contrast with other areas, either the path of the variation of normative feldspar composition, the position of the N and O points on the curve, or the Q values of the volcanic rocks of eastern China are distinctly different. The basalts and andesites of Japan (5, 4, 3) are richest in an and poor in or. Q is present in all of the rocks, but without ol and ne. The or and ab content of volcanic rocks of Kuan-yin-shan of Taiwan (a, b, c) are higher than those of Japan. The Q value in the Kuan-yin-shan basalts is negative. These basalts contain normative ol but no ne. In comparison, for the volcanic rocks of eastern China, normative ne is present from A to N, and ol is present from A to O. They appear later than those of the Circum-Japan Sea region, and the accompanying negative Q value is also greater in those of eastern China. As a whole, the volcanic rocks of eastern China, are high in alkalies, especially K_2O, so that or is high. They have the largest negative Q values, and the N and O points appeared later than the other series.

The Variation of the Normative Pyroxene Composition: Figure 17 shows the variation of the normative pyroxene composition of the volcanic rocks of eastern China (in weight percent), including those of Circum-Japan Sea region and Japan, etc. The normative pyroxene in the acid volcanic rocks of eastern China is gradually enriched in fs, but the wo remains high [Tr: This statement, p. 344 of original, is in apparent contradiction with an earlier statement, p. 342 of the original, where the "residual" amount of wo are mentioned] indicating that the path of differentiation is different from those of the other areas. In the basic type of the alkali series of the Circum-Japan Sea region, the pyroxenes are rich in wo, but in the intermediate types, the en component is increased, accompanied by a decrease in wo. In the acid type both en and fs are notably reduced but fs and wo are increased. [Tr: an apparent error here; it

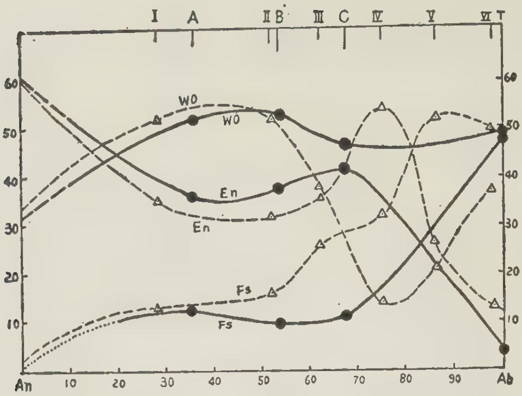


FIGURE 16. Variation of the composition of normative pyroxene with respective to the co-existing feldspar composition

—●— Cenozoic volcanic rocks of eastern China.

--△-- Cenozoic volcanic rocks of the Circum-Japan Sea region

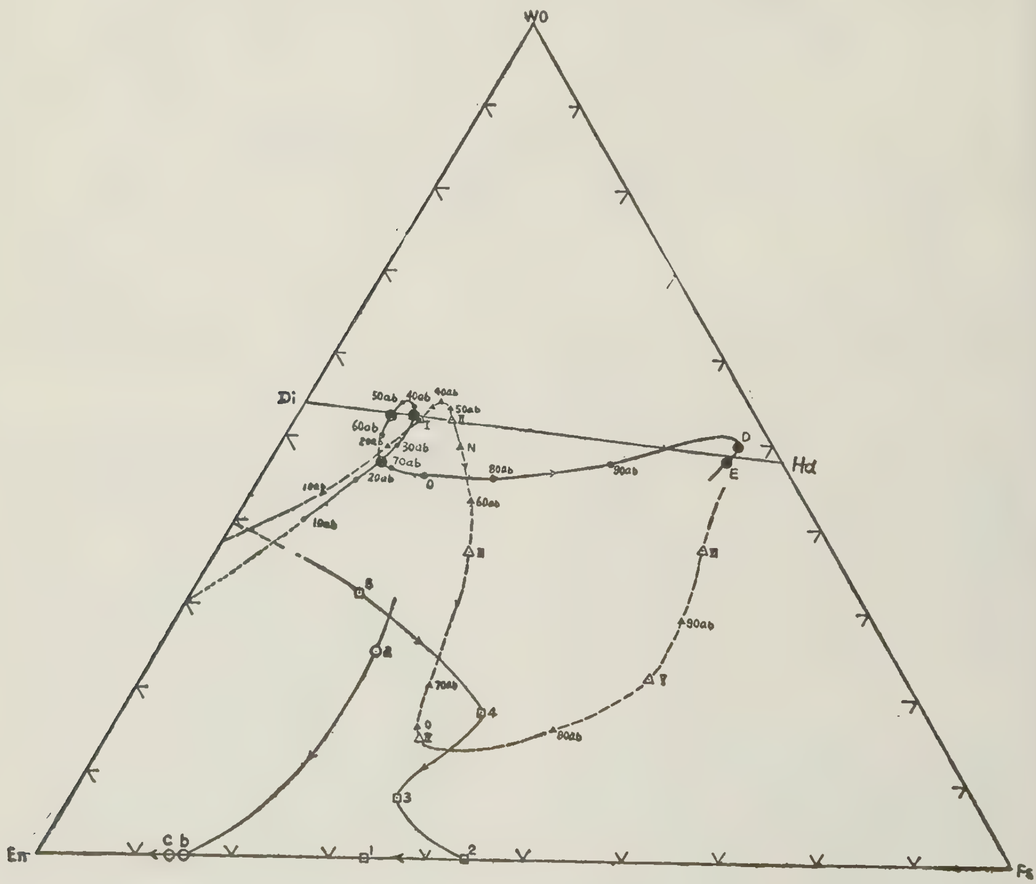


FIGURE 17. Variation of the normative pyroxene composition of the Cenozoic volcanic rocks of eastern China

—●— Volcanic rocks of eastern China

—⊙— Volcanic rocks of Kuan-yin-shan, Taiwan

-△- Alkali volcanic rocks of the Circum-Japan Sea region

—⊡— Volcanic rocks of Japan

TABLE 5C. The Zavaritsky value of the volcanic series of eastern China and Kuan-yin-shan of Taiwan

Rock type	A	B	C	D	E	a	b	c
a	11.9	10.5	12.9	18.7	13.9	8.0	11.1	10.9
c	3.0	4.8	2.9	1.6	1.8	8.8	8.2	5.9
b	35.1	29.2	24.0	4.5	4.2	23.8	13.9	13.0
s	50.0	55.5	60.2	75.2	80.1	59.4	66.8	70.2
a′	...	...	...	...	...	...	14.3	32.8
f′	32.5	37.6	37.2	61.0	80.8	33.8	33.2	28.6
m′	42.5	42.4	37.5	6.0	3.2	53.2	52.5	38.6
c′	25.0	20.0	25.2	33.0	16.0	13.0	...	...
n	75.0	71.4	62.1	64.5	73.5	68.4	74.3	77.5

NOTE: Rock type A, B, C, . . . are the same as in Table 5A; and rock type a, b, c, are the same as in Table 5B.

TABLE 6C. The Zavaritsky value of the volcanic series of Japan and the Circum-Japan Sea region

Rock type	5	4	3	2	1	I	II	III	IV	V	VI	VII
a	4.8	5.9	8.4	9.1	8.3	8.9	10.7	13.3	18.3	19.5	19.2	15.4
c	10.9	9.9	8.0	6.7	2.0	5.7	5.9	5.6	3.8	2.0	0.2	0.1
b	26.4	21.4	12.7	8.2	5.4	35.0	26.1	18.2	9.2	5.7	5.4	4.7
s	57.9	62.8	70.9	76.0	84.3	50.4	57.3	62.9	68.7	72.8	75.2	79.8
a′	...	...	...	...	58	...	...	...	...	...	...	...
f′	44	49	56	66	41	34	39	47	61	75	68	82
m′	37	38	38	34	1	42	39	31	26	12	7	6
c′	19	13	6	0	...	24	22	22	13	13	25	12
n	88	85	75	72	79	75	71	72	62	61	59	59

NOTE: based on Zavaritsky (1954): The petrochemical study of igneous rocks, 350 pages. Rocks types 5, 4, 3 . . . are the same as in table 6A and I, II, III . . . are the same as in table 6B.

TABLE 7A. The average composition of basalts of various parts of the world (regional average)

Composition \ Region	C	A	Z	M	H	P	I	J	D	S	T	O	B
SiO_2	47.56	49.03	47.7	47.5	48.35	46.57	48.7	48.34	51.3	49.8	47.46	49.98	52.68
TiO_2	2.19	2.20	2.3	2.25	2.77	2.96	1.4	1.22	2.0	1.7	2.71	2.87	1.23
Al_2O_3	14.94	16.69	15.8	10.42	13.18	14.93	1.6	1.88	13.9	15.0	13.89	13.74	14.56
Fe_2O_3	4.75	3.60	5.3	4.05	2.35	3.68	4.2	3.67	3.3	2.7	3.58	2.37	2.91
FeO	6.62	7.09	8.8	6.73	9.08	8.07	6.5	6.40	10.1	10.2	9.38	11.60	7.70
MnO	0.14	0.29	0.2	0.12	0.14	0.17	0.2	0.19	0.3	0.2	0.22	0.24	0.32
MgO	7.00	5.65	4.7	6.35	9.72	7.84	7.6	5.13	5.5	0.5	6.79	4.73	6.15
CaO	8.50	9.42	9.9	8.86	10.34	10.76	11.2	10.22	9.8	10.9	9.83	8.21	10.98
Na_2O	3.60	3.51	3.4	3.10	2.42	2.67	2.6	2.66	2.8	2.2	2.90	29.2	2.39
K_2O	2.44	2.03	1.5	1.54	0.58	1.02	0.7	0.94	0.7	0.6	1.01	1.29	0.89
P_2O_5	0.67	0.70	0.4	0.25	0.34	0.34	0.3	0.38	0.3	0.2	0.43	0.78	0.19
H_2O	1.82	...	...	3.83	0.73	0.95	...	2.28	...	...	1.48	1.22	...
MgO/FeO	1.06	0.79	0.53	0.94	1.07	0.97	1.16	0.80	0.54	0.04	0.72	0.40	0.80
MgO/CaO	0.85	0.6	0.47	0.71	0.94	0.72	0.67	0.50	0.56	0.04	0.69	0.57	0.56
Q	...	...	...	...	...	...	...	0.06	3.24	2.34	0.84	2.16	3.90
Or	14.47	11.68	8.89	9.45	3.34	5.56	3.89	5.56	3.89	3.34	5.56	7.78	5.56
Ab	23.58	26.72	26.82	27.24	20.34	22.53	2.20	23.58	23.58	18.34	23.06	24.63	20.44
An	17.24	24.19	23.35	27.25	23.35	25.85	31.69	26.97	23.35	29.61	23.91	20.57	26.13
Ne	3.69	1.42	1.14	...	...	...	...	...	...	...	...	...	...
Di	16.58	14.90	19.32	13.12	21.04	18.07	17.79	9.70	19.26	19.20	18.14	12.03	22.63
Hy	...	...	...	...	14.02	5.45	10.64	15.31	17.22	20.77	12.86	20.72	14.51
Ol	10.02	14.49	2.75	13.55	7.66	2.71	4.47	...	...	...	...	...	...
Mt	6.73	5.10	7.66	6.03	3.25	5.34	6.03	5.57	4.87	3.94	5.57	3.48	4.18
Il	3.26	3.95	4.26	4.56	5.16	5.47	2.73	2.28	3.19	3.19	7.45	5.47	2.28
Ap	1.68	1.65	1.01	0.67	0.67	2.02	0.67	1.01	0.67	0.33	1.01	2.02	0.34
Wt% Or	26	19	15	15	7	10	7	9	8	5	11	15	11
Wt% Ab	43	43	45	42	43	42	38	35	46	20	47	47	39
Wt% An	31	38	40	43	50	48	55	56	46	65	42	38	50
Wt% Wo	53	51	51	49	33	40	33	20	27	26	39	18	31
Wt% En	38	31	24	39	47	44	50	52	38	40	38	36	41
Wt% Fs	9	18	25	12	20	16	17	28	35	34	23	46	28

NOTE: C (Eastern China, av. of 71) this paper; A (Circum-Japan Sea region, av. of 44) based on Tomita [45], 1935, minus 6 for eastern China, for this is the new average; Z (East Otego, New Zealand, av. of 24) Benson [46], 1941, 1944; M (Sakhalin, av. of 4) Yagi [47], 1953; H (Hawaii Islands, av. of 53) MacDonald [48], 1949; P (Pacific Islands, av. of 116), Green and Polderwaart, 1955; I (Indonesia, av. of 12) Willems [50], 1945; J (Japan, av. of 36) Iwasaki [51], 1937; D (Deccan Plateau, India, av. of 16) Tyrrell and Sandford [52], 1933; S (Siberia, av. of 17) Walker and Polderwaart [53], 1949; T (North Atlantic islands, av. of 33) Washington [54], 1932; O (Oregon, av. of 6) Washington [54], 1932; B (northern England, av. of 8) Holmes and Harwood [55], 1929.

TABLE 7B. The Niggli and Zavaritsky value of the basalts of various parts of the world (regional average)

Niggli value	C	A	Z	M	H	P	I	J	D	S	T	O
Si	111.8	115.5	112.0	112.3	106.4	104.4	108.7	118.0	114.8	114.8	110.0	127.7
al	20.6	23.2	21.8	23.4	17.0	19.6	21.8	26.9	20.0	20.3	18.9	20.6
fm	46.0	42.2	43.3	44.0	52.7	47.6	44.8	38.7	47.0	47.0	48.6	47.6
c	21.5	23.7	24.9	23.0	24.3	25.7	26.8	26.5	25.5	27.0	24.4	22.4
alk	11.9	10.9	10.0	9.6	6.0	7.1	6.6	7.9	7.5	5.7	8.1	9.4
mg	0.53	0.47	0.38	0.52	0.60	0.55	0.56	0.48	0.42	0.47	0.48	0.37
k	0.31	0.27	0.23	0.24	0.13	0.19	0.14	0.13	0.13	0.14	0.19	0.23
al–alk	8.7	12.3	11.8	13.8	11.0	12.5	15.2	17.0	12.5	14.6	10.8	11.2
C–(al–alk)	12.8	11.4	13.1	9.2	13.3	13.2	11.6	9.5	13.0	12.4	13.6	11.2
qz	–35.8	–28.1	–28.0	–26.1	–17.6	–24.4	–17.7	–17.6	–5.7	–12.0	–22.4	–9.9
Zavaritsky value	C	A	Z	M	H	P	I	J	D	S	T	O
a	11.5	10.5	10	9.6	5.9	7.2	6.7	7.8	7.0	5.6	8.0	9.7
c	4.2	6.0	5.9	6.9	5.5	6.3	10.3	9.5	5.7	7.2	5.3	5.0
b	28.3	25.4	25.5	26.4	33.0	31.0	26.2	23.0	27.9	29.2	30.5	25.5
s	54.5	58.1	58.6	57.1	55.6	55.5	56.8	59.7	59.4	58.0	56.2	59.8
f'	36.8	40.0	41.2	39.7	31.6	37.0	37.9	43.9	45.3	42.8	40.3	49.3
m'	41.8	38.1	32.8	43.2	48.4	43.0	49.4	40.0	33.0	37.6	38.0	31.0
c'	21.4	21.9	26.0	17.1	20.0	20.0	12.7	16.1	21.7	19.6	21.7	19.7
n	69.0	72.7	77.4	75.3	86.6	81.0	85.7	81.8	86.5	85.3	81.0	77.4
a/c	2.71	1.75	1.69	1.39	1.07	1.12	0.65	0.82	1.23	0.77	1.50	1.94
Q	–16.7	–10.8	–8.7	–11.9	–6.1	–9.7	–10.1	–6.7	–0.9	–2.2	–8.9	–4.8

NOTE: The regional designation C, A, Z, . . . are the same as in Table 7A.

should read "In the acid type en is notably reduced but fs and wo are increased."] The range of variation of the normative pyroxene composition is also relatively large. In the basic volcanic rocks of Japan and of Kuan-yin-shan of Taiwan, the pyroxene is poor in wo and the path is toward enrichment of en. In the intermediate type, the wo is used up so that it takes a reverse trend as compared to the trend of those of eastern China and the Circum-Japan Sea region. This is a most notable difference between the alkalic series and non-alkalic series. In 1933, Kennedy [67] stated that because the pyroxene in the olivine basalt magma is richer in calcium than the residual magma, the final stage of the magma are enriched in alkalies. Later Hess [68] in 1941, Edwards [69] in 1942 and Kuno [61] in 1950, in the study of the path of crystallization of the pyroxene, agreed that the path is the simplest in alkali-magmas shown clearly in the wo-en-fs diagram. In the alkali series, there is no rhombic pyroxene or pigeonite, and the only pyroxene is a monoclinic pyroxene other than pigeonite. The path of its crystallization goes from diopside towards the calcium-iron pyroxene. The pyroxene of the alkalic series is always richer in the wo content than in the calc-alkalic series, therefore, the pyroxene composition is situated near the di-hd line. The pyroxene composition of the volcanic series of eastern China is clearly that of an alkalic series. Points O and N [Tr: Presumably refers to Figure 17, but point N is not shown for the Chinese rocks] which represent the appearance or disappearance of olivine and nepheline respectively along the trend of variation of the pyroxene composition, are derived by graphic method from Figure 16. Figure 16 shows that the wo component of the pyroxene varies only slightly in the volcanic rocks of eastern China, which is in marked contrast with those of the alkalic volcanic rocks of the Circum-Japan Sea region. From the diagram, the pyroxene composition corresponding to the olivine-quartz index (point O) is wo:en:fs = 50:38:12, and the pyroxene composition corresponding to the nepheline-hypersthene index (point N) is wo:em:fs = 45:38:17. The points O and N along the variation curve of the pyroxene composition marked the stages where a particular pyroxene was accompanied by normative olivine (before reaching point O) or by normative quartz (after reaching point O). Or that it is accompanied by normative nepheline (before reaching point N) or by hypersthene (after reaching point N). The appearance of point O and N of the volcanic series of eastern China, on the variation diagram, are later than those of the alkalic series of the Circum-Japan Sea region owing to their more alkalic characteristic (tables 5C and 6C).

Zavaritsky Petrochemical Diagrams: Figure 18 is the Zavaritsky chemical variation diagram of the volcanic series of eastern China and Kuan-yin-shan of Taiwan. Included for comparison are those of Japan and the Circum-Japan Sea region given by Zavaritsky [57, p. 205, fig. 61]. It shows the chemical characteristics of the Cenozoic volcanic rocks of various areas of eastern Asia.

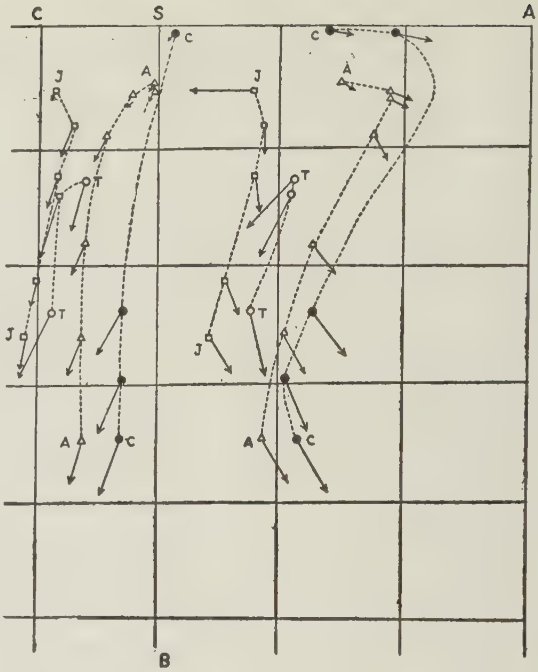


FIGURE 18. The chemical variation diagram of the Cenozoic volcanic rocks of eastern China

C Volcanic rocks of eastern China including Hsin-chu of Taiwan.
A Alkalic series of the Circum-Japan Sea region.
T Volcanic rocks of Kuan-yin-shan, Taiwan.
J Volcanic rocks of Japan.

In the alkalic area (SAB), the alkali-atomic index of the volcanic series of Japan (J), Kuan-yin-shan of Taiwan (T), the Circum-Japan Sea region (A), and eastern China (C) follow smooth curves. They agree well with the variation diagram of the normative mineral composition, that is, the alkalic characteristics increase towards the right, the strongest being represented by those of eastern China. During the differentiation, the intermediate and acid rocks of eastern China and the Circum-Japan Sea region show gradual decrease of magnesia and increase of iron as shown by the vectors. However, iron decreases, accompanied by excess of alumina in the volcanic series of

Japan and Kuan-yin-shan of Taiwan, a sharp and notable contrast between an alkalic and a non-alkalic series. Furthermore, the volcanic series of eastern China is more strongly alkalic than those of the Circum-Japan Sea region.

In the calcic area (SCB) the atomic index of the calcic plagioclase of these series also follows smooth curves and increases towards those of Japan. In the acid rocks of eastern China, due to the gradual decrease of Al_2O_3 the atomic index of the calcic plagioclase has a negative (c) value. Those of the Circum-Japan Sea region, the c value, although not negative, is less than 0.2, again indicating the alkali characteristics of the series. The vectors indicate the relative quantities of potassium between the volcanic series of eastern China and its adjacent areas, especially with reference to the basic rock types. The potash content is higher in those of China than in those of the Circum-Japan Sea region; it is also higher in those of Kuan-yin-shan of Taiwan than in those of Japan. The iron-magnesium atomic index shows that the rock series of China and the Circum-Japan Sea region were derived from iron and magnesium rich ultrabasic magmas. The calc-alkalic series of Kuan-yin-shan of Taiwan and Japan were derived from basic magma of lower iron and magnesian content. The difference between the two series is evident. The more magnesia-rich rocks of Kuan-yin-shan of Taiwan indicate that the parent magma is an olivine basalt type.

Comparison with Basalts of Various Parts of the World

The chemical and mineral composition of the basalts of eastern China have been described and have been compared with those of the Circum-Japan Sea region, Japan and New Zealand. In order to be complete, the averages of the well-known basalts of various parts of the world are given in Table 7A for comparison. They include those of the adjoining areas of China, namely, Japan, Indonesia, and Sakhalin; the oceanic basalts of Hawaii, Pacific and the northern Atlantic; and the basalts of continental areas such as India, Siberia and Oregon, etc. These include olivine basalts and tholeiitic basalts (tables 7A and 7B).

From Table 7A, it can be seen that the most striking feature of the basalts of eastern China is their strong alkalic character, especially the amount of K_2O. The $Na_2O + K_2O$ content is as much as 6.0 percent with K_2O 2.4 percent. Lime is low but is slightly higher than the Oregon basalts of North America. Other oxides vary within the limits of variation of other basalts, and thus no further discussion is necessary. Figure 19 shows this relation

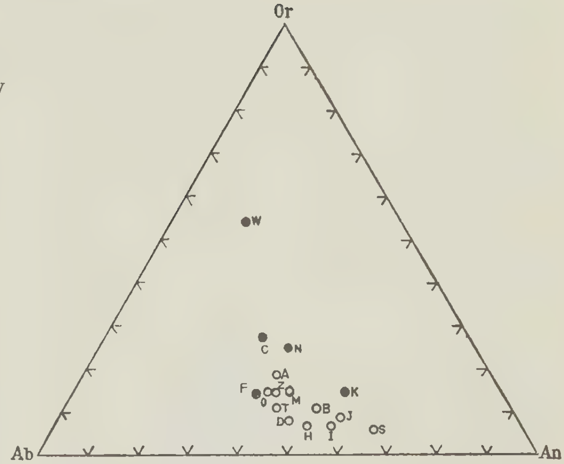


FIGURE 19. Normative feldspar composition (in weight percent) of basalts of various part of the world

● Basalts of various parts of the world A,0, Z... same as in Table 7A.

o Basalts of eastern China, F,N.K... same as in Table 2A.(See March issue I.G.R., p.205)

very clearly. The basalts of eastern China have the highest normative or content, more than any other region. The basalts of southern China (F) are lower in or than Sakhalin (M), New Zealand (Z), and Oregon (O), but are highest in ab. The basalts of northern China and southern Manchuria are more alkalic than those of the Circum-Japan Sea region (A), and New Zealand (Z). Although normative an is higher in the Kuan-yin-shan, Taiwan basalts than other Chinese basalts, their normative or content is clearly higher than those other parts of the world such as Japan (J), England (B), Siberia (S) and Hawaii (H), and comparable to those of New Zealand (Z) and Sakhalin (M). From the diagram of the normative feldspar composition, it is clear that the basalts of eastern China are strongly alkalic and particularly high in K_2O. This feature is most clearly shown on the variation diagram of the Zavaritsky value. Figure 20 shows clearly that the alkali atomic index of the basalts of eastern China is greater than those of various other parts of the world. Even those of southern China are comparable to the alkalic rocks of the Circum-Japan Sea region and New Zealand. The iron-magnesium atomic index, or the silica atomic index, lie within the mid-range of those of other parts of the world. In China, the alkali atomic index is lowest in southern China (F), increasing in northern China and southern Manchuria (N), to values greater than those of the alkali rocks of Sakhalin and New Zealand, and reaches the maximum in northern Manchuria (W). The high potash content of the basalts of eastern China is also evident from the vectors in the calcic area of the diagram, a feature that is, as mentioned before, characteristic of the

FIGURE 20. Comparison of the chemical composition of basalts of the world
⊙ Basalts of various parts of the world, J, I, D. . . same as in Table 7A.
● Basalts of eastern China, F, N, C. . . same as in Table 2A. (See March issue I.G.R.,p.205)

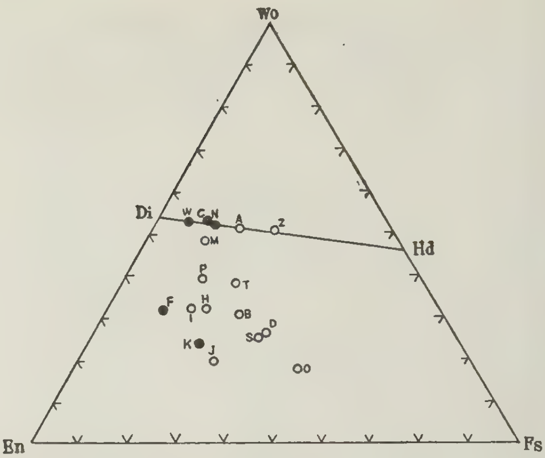


FIGURE 21. Normative pyroxene composition of the basalts of various parts of the world (weight percent)
o basalts of various parts of the world M,A,Z. . . same as in Figure 4 See March Issue of I.G.R. p. 212.
● basalts of eastern China N,F,K. . . same as in Figure 2, See March Issue of I.G.R. p. 209.

basalts of eastern China.

PARENT MAGMAS

The Relationship between the Olivine Basalt and the Tholeiitic Basalt Magmas

In 1933, Kennedy [67] distinguished, on the basis of the chemical composition, the olivine basalt magma from the tholeiitic magma. The former is distributed in the oceanic regions and differentiates into trachyte and phonolite etc., the parent magma of alkalic rocks. The latter is distributed in the continental areas and differentiates into andesites, and rhyolites, etc., the parent magma of calcic series. Later, Kennedy and Anderson [70] postulated that these two types of magmas were derived from divergent tectonic environment, from the different layers of the crust. The chemical and mineral composition of the basalts of eastern China not only shows regional variation from southern China, northern China and southern Manchuria, northern Manchuria and Taiwan, but are also different from those of the adjacent areas such as the Circum-Japan Sea region and Japan. These rocks are distinct whether they are compared with the tholeiitic basalts of the continental areas or the olivine basalts of the oceanic areas. The difference can be easily seen from Figures 19 and 21 in the variation diagrams of normative feldspars or of normative pyroxenes. For example, in Figure 21, the basalts of eastern China, New Zealand, the Circum-Japan Sea region, etc., are rich in normative wo; the plots are near the di-hd line. The tholeiitic basalts of Oregon, Deccan of India, and Siberia, etc., are poor in normative wo; the plots are scattered in the central part of the di-hd-fs-en area. According to Tilley [71] the olivine basalts of Hawaii consist of two types, the olivine basalt and the tholeiitic basalt. According to Walker and Davidson [72] olivine basalt and tholeiitic basalt occur together on the Faeroe Island, so that the normative pyroxene composition lies in the intermediate position of the two magma types. In the olivine basalts of southern China, the early stage is close to the composition of olivine basalt but the late stage is closer to the tholeiitic basalt, so that the normative pyroxene, enriched in en, also occupies the central part of the diagram. As mentioned before, the alkali basalts of the Circum-Japan Sea region, Sakhalin and New Zealand are differentiates of olivine basalt magmas. The modal mineral composition of the basalts of eastern China is characterized by the large amounts of olivine and titanaugite, together with plagioclase, potassic andesine and anorthoclase, etc. Chemically they are also similar to the olivine basalt magma type. The differentiation of the olivine basalt of Kuan-yin-shan of Taiwan gives rise directly to two-pyroxene andesite and hornblende andesite, so that chemically the magma is also similar to tholeiitic basalt. This can perhaps indicate that there are two types of magma as suggested by Kennedy. Considering the basalts of the world, the SiO_2, Al_2O_3, $Na_2O + K_2O$, and the MgO: CaO and the MgO: FeO ratios of Table 7A, or the variation of the normative pyroxene composition of Figure 21, there is no sharp break of two distinct types of

magma between the basalts of eastern China, and adjacent areas such as Japan, or other parts of the world. With respect to the normative nepheline or quartz, which indicates the degree of saturation of the magma with respect to silica, the variation is also gradational, changing from that of an olivine basalt to that of a tholeiitic basalt. This feature is more clearly seen on the Zavaritsky diagram. Table 7B shows that Q grades from -16.7 to -0.9, the a : c ratio grades from 2.71 to 0.65. They do not indicate two sharply distinct types of magma. There may be two different kinds of olivine basalt magmas in various parts of China. The modal mineral composition shows that they all belong to the olivine basalt type. From the distribution of types of basalts in various parts of the world, not only the oceanic Hawaiian area has tholeiitic basalt, but also within the continental Deccan [73] and Karroo [74], tholeiitic basalts grade into olivine basalt. Thus basaltic magmas do not consist of two individual parent magma types which are separate in origin and distribution. There are many discussions regarding the variation of the composition and derivation of basaltic magmas. Bowen [90] and Kuno [74] believed that owing to crystal sorting, by removal of early crystallized olivine and basic plagioclase, a tholeiitic basalt magma can be derived. Tomita [45] postulated that a tholeiitic magma can be derived if assimilation of siliceous material by an olivine basalt magma takes place. Barth [75] described the derivation of an olivine basalt, or a tholeiitic basalt magma, from the differentiation of a "plateau basalt" depending on the trend, and the diffusion of the alkalic components. Tilley [71] on the basis of an absence of sialic material, and the relation of the volcanic sequence and association of Hawaii, believes that the parent magma of the basalts of the world is a relatively alkali-poor tholeiitic olivine basalt, which by differentiation, gives rise to a silica-saturated hypersthene basalt and an alkali-rich olivine basalt and its associated rock types. Kuno [61] on the basis of his study of the volcanic rocks of Hakone, considers the parent magma of the basalts of the Hakone area as similar to that of a tholeiitic basalt magma, but the modal mineral composition is that of an olivine basalt, which by assimilation gives rise to the hypersthene series. If only simple local differentiation takes place, then the pigeonite series was derived. He also pointed out that the typical olivine basalt, as that of the Circum-Japan Sea region with 3 percent Na_2O and 1.5 percent K_2O, is more alkalic than the parent olivine basalt magma of the Hakone area. The chemical and mineral composition of the basalts of various parts of the world, according to Kuno, range between those of the Circum-Japan Sea region and those of the Hakone area of Japan . Concerning the basalts of China, the parent magmas are all of the olivine basalt type, although they differ somewhat chemically. The basalts of Nanking and Hainan Island are of interest because they contain relatively high amounts of SiO_2 and Al_2O_3, and are rich in alkalies. Quartz basalt and hypersthene basalts occur there, indicating possible contamination by sialic material. In the northern Manchuria region, Ogura [19] and Gori [76] described the occurrence of granite xenoliths which show various degrees of fusion in the volcanic rocks of Wu-Yun and Er-tung-chi volcanoes. Knopf [77] described a similar occurrence of the olivine basalt of the Owen Valley of California in North America. Owing to the direct melting of granite xenoliths in basaltic magma, glass developed at the contact between orthoclase and quartz, accompanied by crystallites of hypersthene. Goranson [78] proved experimentally that most of the powdered granite, in the presence of water under confined pressure, melts at 700°C. This indicates that at a depth of several thousand meters, granite containing proper amounts of water can melt by fusion. Since the temperature of the basalt magma is higher than 700°C, melting of granitic material must be possible, and result in an increase of SiO_2, K_2O and Na_2O. Thus assimilation by the basaltic magma would change the composition of the original melt, and various amounts of contamination could result in differences in composition; therefore magmas are not limited only to two different types.

Relation Between the Origin of the Alkali Basalt Magma and the Non-alkali Basalt Magma

From Hainan Island through Nanking to northern China and southern Manchuria the basalts of eastern China show gradual under-saturation with respect to silica and increase of alkalies. Nepheline basalt occurs in Shantung and Liaoning. In Inner Mongolia and northern Manchuria, assimilation is more extensive as indicated by the occurrence of leucite basalt. The volcanic rocks of Tan-shui and Kuan-yin-shan of Taiwan consist of olivine basalt, two pyroxene andesite and hornblende andesite of a non-alkalic series. In the adjoining areas such as Liu-ch'u of Hsin-chu and Ma-wu-tu and Ts'ao-ling etc., feldspathoid-bearing rock, leucite, basanite, and analcite basanite, for example, occur. This is of interest in regard to the origin of the alkali rocks. From the petrogenetic point of view, the origin of alkali rock series is commonly attributed to differentiation, diffusion of volatile substances and heat, or assimilation. Those [investigators] considering tectonic environment dealing with the relation of the interior of the earth to the origin of tectonic structures have reached similar conclusions. Early in 1914 Winkler [79], in studying the Tertiary volcanic rocks of the eastern Alps, pointed out that the calc-alkalic rocks occur in areas of faults and that the alkalic rocks with numerous sedimentary inclusions lie in a folded belt. Thus Winkler believes that calc-alkalic rocks were derived from the assimilation of siliceous sediments by

an alkalic magma. Later in 1939, Barth [80] also considered the geologic environment to be a decisive factor controlling the trend of development of a rock series. He considered the primitive basalt to be an olivine basalt of intermediate alkali content. In the oceanic region where sialic material is lacking, alkalic series can be derived by simple fractional crystallization. In the continental areas, due to contamination by sialic material, differentiation gives rise to trachyte and rhyolite series. In the folded belt, incorporation of highly siliceous sediments and subsequent differentiation, would give rise to andesite and rhyolite of the calcic series. This explains the derivation of various kinds of parent magma due to the different geological tectonic or sedimentary environment or various conditions of assimilation. Harker[81] and Tyrrell [82] stressed the relation of the composition of the magma with structure. They indicated that alkalic magmas were developed in areas of tension fractures, the faulted region, whereas the calc-alkalic magmas were developed in folded orogenic belt under compressive stress. Tomita [45], on the other hand, indicated that alkalic rocks were found in areas of deep ruptures, whereas the calcic rock series follow the folded geosynclinal belt. As far as the structural relationship is concerned, there is no definite rule; for instance, olivine basalt and nepheline basalts are developed in the east African graben, but during the igneous activity between Tertiary and Pleistocene the area suffered transverse fracturing movement repeatedly [83]. The alkalic volcanic series of east Otago, New Zealand were extruded during the local folding and transverse faulting of the earth's crust. The outpouring of alkalic volcanic lava was greatest during the strongest period of folding [84]. Alkali basalts occur in orogenic folded belt in Taiwan. In Java and in the Malay archipelago, leucite basanite and trachyandesite [85, 86] accompanied by inclusions of metamorphic limestone, occur with the pyroxene andesite. The assimilation of limestone by the pyroxene andesite results in local desilication and produces alkalic minerals. The alkali basalt of Taiwan has not been studied petrologically. It may be related to assimilation.

The Problem of the Varied Composition of Parent Olivine Basalt Magmas

The difference in composition, and the variations of the olivine basalt magmas of various parts of the world, which can be directly proven by petrological studies, are only limited to that of assimilation. The composition of the primitive basalt magma conceivably should be directly related to the environment and its restrictions. Daly [87] maintains that there is a layer of glassy basalt in the earth's crust at a depth of 60 km, therefore the magma of basalts of the world has the same composition. According to recent geophysical investigations, sial of the continental region is 25 to 40 km thick, about 60 km in the high mountainous region, and averages about 33 km [87]. The layer is not homogeneous in character. Below this should be a sima layer of olivine-rich material of greater density. The core lies at depth of 2,900 km. Zavaritsky [89] in 1946 pointed out that the location of Recent volcanoes is related to deep ruptures and deep earthquake centers. This would indicate that the rupture along which the magma rises may reach a depth of 150 to 800 km, hence the source of the magma must have come from a depth of at least 100 km. It would seem logical that the source of the basalt magma lies in the peridotite layer of sima, and is not related to the basalt layer whose actual existence cannot be proven. Bowen's [90] hypothesis that the primary basalt magma was derived by selective melting of a feldspar-bearing peridotite (similar to stony meteorite in composition), seems more plausible. Along the deep rupture of the earth's crust, heat and dissolved gases would melt a portion of the ultrabasic sima shell. Since the sima shell may not be of a uniform character, and since heat and dissolved gases may vary in intensity and concentration from place to place, the primary basalt magma resulting from local melting would have different compositions. In addition, the basalt magma may originate from different depths of the peridotite layer, and the different conditions of assimilation on its journey upward, together with such varied geological environments, result in basalt magmas of varied composition. Because these magmas originated from the same peridotite layer of the sima by selective melting, they all have more or less an olivine basalt type of composition. The variation of the composition of the olivine basalt magmas is related to the source environment and the type and quantity of assimilation.

CONCLUSIONS

1. The predominant Cenozoic (between Eocene and Pleistocene) volcanic activity was represented by the extrusion of basalts, continued into the Recent period. Their distribution is mainly in the eastern part, in the coastal provinces. On the basis of more than 70 chemical analyses, and by petrographic calculations and graphic representations, the basalts of eastern China are the most alkalic in the world. The striking characteristics lie in their high K_2O content. These rocks clearly belong to an alkalic series (fig. 1).

2. On the basis of the characteristics of the chemical composition and their variation, the basalts of eastern China can be divided into four regions. The average chemical composition and petrochemical characteristics of each region are shown in Tables 8 and 9.

TABLE 8. Regional average chemical composition and norm (See figs. 2, p.209 and 3, p.211, March issue of I.G.R.)

Region	Northern Manchuria (W)	Northern China and Southern Manchuria (N)	Southern China (F)	Taiwan		Eastern China (C)
				Kuan-yin-shan (K)	Hsin-chu (20)	
Composition	14 samples	30 samples	22 samples	3 samples	5 samples	71 samples*
SiO_2	50.39	45.45	49.20	50.14	45.48	47.56
TiO_2	2.40	2.38	2.02	1.70	1.07	2.19
Al_2O_3	14.32	14.80	15.45	18.78	13.16	14.94
Fe_2O_3	3.49	4.43	6.23	2.34	3.62	4.75
FeO	5.43	8.08	5.95	6.20	6.83	6.62
MgO	6.90	7.31	5.30	7.29	12.82	7.00
CaO	6.74	9.25	8.58	9.60	8.57	8.50
Na_2O	3.48	3.83	3.47	2.44	3.13	3.64
K_2O	5.03	2.01	1.43	1.70	2.19	2.44
P_2O_5	0.97	0.74	0.07	—	—	0.67
MnO	0.13	0.06	0.46	0.09	0.15	0.14
H_2O	0.92	1.91	3.40	0.87	2.43	1.82
Q	—	—	1.26	—	—	—
Ne	6.25	8.24	—	—	8.52	3.69
Wt% Or	53.4	25.2	13.9	15.2	33.0	26.2
Wt% Ab	31.7	37.4	49.0	30.0	27.0	42.6
Wt% An	14.9	37.4	37.1	54.8	40.0	31.2
Wt% Wo	52.8	52.0	31.0	24.3	52.4	52.5
Wt% En	79.7	34.6	58.0	52.5	37.7	38.0
Wt% Fs	7.5	13.4	11.0	23.2	9.9	9.5

* Average of alkali basalts which does not include the three analyses from Kuan-yin-shan.

3. The regional characteristics of the distribution of the basalt types of eastern China seem to be closely related to tectonic units. On the basis of the rock type and its constituent minerals, the distinct regional differences are: 1) The northern Manchuria region--predominantly leucite basalt; trachybasalt also present. Minerals present beside olivine, pyroxene, and plagioclase, are leucite, anorthoclase and biotite, etc. Their distribution coincides generally with the Variscan folded, granitized region of northern Manchuria. 2) The northern China and southern Manchuria region--predominantly trachyandesitic basalts occasionally containing nepheline and analcite, with some limburgite. Their distribution corresponds essentially to the Sino-Korean massif of the Pre-sinian crystalline shield. 3) the southern China region--predominantly olivine basalts succeeded at later stages by tholeiitic olivine basalts; associated occasionally with hypersthene basalt or trachybasalt. The minerals are chiefly olivine, pyroxene, plagioclase, occasionally with hypersthene, quartz and anorthoclase. Their distribution corresponds to the Caledonian folded belt and the southern China massif. 4) The Taiwan region--essentially olivine basalt with its differentiated pyroxene andesite and hornblende andesite. Alkalic basalt also occurs. The former contains olivine, pyroxene, plagioclase, hypersthene and hornblende etc., the latter contains besides olivine, pyroxene and plagioclase, leucite, orthoclase and biotite, etc. Their distribution corresponds to the Himalayan folded belt of Taiwan.

4) If the basalts and their differentiates of China are compared with those of the adjacent areas such as the Circum-Japan Sea region and Japan, the chemical aspects of the rock series show regular geographic variation. Based on

Table 9. Magma types and the Zavaritsky value (figures 4,5,6,7,8)
(See March issue of I.G.R. pp. 212-215)

Region		Northern Manchuria (W)	Northern China and Southern Manchuria (N)	Southern China (F)	Taiwan: Kuan-yin-shan (K)	Taiwan: Hsin-chu (20)	Eastern China * (C)
Niggli value	Si	130.0	101.6	122.6	118.0	93.6	111.8
	al	21.1	19.5	22.6	26.0	16.0	20.6
	fm	44.1	47.2	43.9	41.8	56.0	46.0
	c	18.0	22.2	22.9	24.2	19.0	21.5
	alk	16.8	11.1	10.6	8.0	9.0	11.9
	mg	0.59	0.52	0.45	0.61	0.68	0.53
	k	0.49	0.25	0.21	0.31	0.32	0.31
	al–alk	4.3	3.4	12.0	18.0	7.0	8.7
	$\frac{alk}{al-alk}$	5.0	1.3	0.9	0.4	1.3	1.4
	Qz	–37.2	–42.8	–19.8	–14.0	–42.4	–35.8
Magma types		Lampro-sommaitic	Nepheline syenite-gabbroic	Syenite-gabbro-dioritic	Gabbro-miharaitic	Ferro-magnesian gabbro-potassic amphibolitic	Nepheline syenite-gabbro-dioritic
Zavaritsky value	a	14.6	11.3	9.9	8.0	9.5	11.5
	c	2.0	4.2	5.5	8.8	3.6	4.2
	b	25.5	30.9	26.0	23.8	36.2	28.3
	s	57.9	53.6	58.6	59.4	50.7	54.8
	f'	31.5	36.7	42.8	33.8	27.6	36.8
	m'	45.0	40.7	35.2	53.2	54.9	41.8
	c'	23.5	22.6	22.0	13.0	17.5	21.4
	n	51.0	74.7	78.8	68.4	68.5	69.0
Classification of rock		Silica under-saturated strongly alkalic type (VI-21-b)	Silica under-saturated alkalic type (VI-22-b)	Silica weakly saturated, weakly alkalic type (V-19-b)	Silica over-saturated weakly alkalic type (IV-15-b)	Silica under-saturated alkalic type (VI-22-b)	Silica under-saturated alkalic type (VI-22-b)

* Average of alkali basalts which does not include the three analyses from Kuan-yin-shan

the chemical indices shown in the following table, the alkali characteristics increase in the order: Japan, Taiwan, the Circum-Japan Sea region and eastern China. The volcanic rocks of eastern China are most alkalic (figures 9 through 17).

Index	Japan	Taiwan (Kuan-yin-shan)	Circum-Japan Sea Region	Eastern China
Lime-alkali	65.5 (calcic series)	59.5 (calc-alkalic series)	53.0 (alkali calcic series)	52.0 (alkali calcic series)
Alkali-alumina	-	-	67.8 and 72.2	63.3
Olivine-quartz	20.0	43.0	72.5	76.5
Nepheline-hypersthene	-	-	55.0	59.9
Diopside-corundum	46.5	46.5	-	-

Such variations are most clearly shown in the chemical variation diagram of Zavaritsky (fig. 18). In the alkali area, the alkali atomic index increases in the order: Japan, Taiwan, the Circum-Japan Sea region and eastern China. From the vectors, the calc-alkali series of Japan and Taiwan gradually reach the point of saturation with respect to Al_2O_3, but the alkalic series of the Circum-Japan Sea region and eastern China show decrease of MgO. In the calcic area of the diagram, the anorthite atomic index increases in the order: eastern China, the Circum-Japan Sea region, Taiwan and Japan. The vectors show that the volcanic rocks of eastern China and Taiwan are higher in K_2O.

5. As compared with the basalts of various parts of the world such as Japan, the Circum-Japan Sea region, Sakhalin, Indonesia, the olivine basalts of Hawaii, other Pacific Islands and New Zealand, the tholeiitic basalts of Siberia, Deccan of India, Oregon of North America, northern England and islands of northern Atlantic, the normative feldspars diagram (fig. 19) and the normative pyroxene diagram (fig. 20) show that the basalts of eastern China are highest in alkali content, especially in regard to the far greater content of normative orthoclase. The composition of the normative pyroxene is closest to that of the alkali peridotite. Figure 21, the Zavaritsky diagram, shows that the basalts of eastern China have the highest alkali atomic index and the lowest anorthite atomic index, and the vectors show that they contain the highest value of K_2O.

6. The basalts of southern China and northern Manchuria show clear evidence of contamination and assimilation. Those of southern China show high values of silica, alumina and potassium oxide; the magma progresses towards saturation with respect to silica and resembles the tholeiitic basalt type. Silica, potassium oxide and sodium oxide are high in the undersaturated basalts of northern Manchuria. Leucite, biotite and anorthoclase are usually present. The alkali basalt of Taiwan is also effected by assimilation. The changes in composition of the basalts of eastern China should be directly related to the process of assimilation.

7. Recent geophysical data show that the modern volcanic belts are closely related to the deep-seated earthquake centers and deep ruptures which substantiates the contention that the basaltic magma was derived from the peridotite shell of stony meteorite composition below the depth of 120 km. Hence the basalt magma was derived from the selective melting of the peridotite shell. Within a depth of 800 km of the mantle, the generation of heat and amounts of gases and solutes vary, so that the part that is selectively melted would also have a varied composition. Furthermore, contamination and assimilation would result in different products of differentiation. Because basaltic magma was derived by the selective melting of a part of the peridotite shell, its composition is similar to that of a peridotite, and because of contamination and assimilation basalts do vary in composition.

REFERENCES

1. Tokuda Sadakazu., 1921., BASALT PLATEAU ALONG THE RIVER MURIN, PROVINCE KIRIN, MANCHURIA: Jour. Geol. Soc. Tokyo, v. 28, no. 330, p. 127-136. [Japanese]

2. Barbour, G. B., 1929., THE GEOLOGY OF THE KALGAN AREA: Geol. Surv. China Mem., Ser. A, no. 6.

3. Tung, C., 1923., VOLCANIC REMAINS AND THE DISTRIBUTION OF BASALTS OF WESTERN KIANGSU: Science, v. 8, p. 829. [Chinese]

4. Feng, K. L., 1937., NOTES OF THE LAVA COVERED GOLD PLACER DEPOSITS OF TANGSHAN, CHIHSIA, SHANTUNG: Bull. Geol. Soc. China, v. 17, p. 33-39.

5. Yamanari, B., 1927., PAI-T'OU-SHAN: Jour. Geogr. v. 40, p. 475-477. [Chinese]

6. Teihard De Chardin, P., 1926., ETUDE GÉOLOGIQUE SUR LA RÉGION DU DALAI NOOR: Mem. Soc. Géol. de France, Nouvelle Série, t. III. fasc. 3.

7. Li, C. and Chang, W. Y., 1936., VOLCANIC CRATER OF JÜ-SHAN, YÜ-I-HSIEN, ANHUI. Geol. Notes, Geol. Soc. China,

v. 2, no. 2. [Chinese]

8. Teilhard de Chardin, P., 1937., A MAP OF THE YOUNGER ERUPTIVE ROCKS IN CHINA: Bull. Geol. Surv. China. v. 30, p. 1-52. [Chinese]

9. Yin. T. H., 1936., RECENT VOLCANIC ACTIVITY OF CHINA: Geol. Notes Geol. Soc. China, v. 2, no. 4. [Chinese]

10. Tyrrell, G. W., 1932., THE BASALT OF PATAGONIA: Jour. Geol., v. 41, p. 374-383.

11. Lanick, A., 1908., BEITRAGE ZUR PETROGRAPHIE VON WEST-SHANTUNG, INAUGURAL DISSERTATION, LEIPZIG: Ref. B. Koto (1912).

12. Koto, B., 1912., ON NEPHELINE BASALT FROM YENGÊMEN, MANCHURIA: Jour. Col. Sci. Univ. Tôkyô. XXXII, Art. 6.

13. Lacroix, M. A., 1928., LA COMPOSITION MINERALOGIQUE ET CHIMIQUE DES ROCHES ERUPTIVES ET PARTICULIERE-MENT DES LAVES MESOZOIQUE ET PLUS RECENTE DE LA CHINA ORIENTALE: Bull. Geol. Soc. China, v. 7, no. 1.

14. ______________, 1929., OBSERVATIONS SUR LES LAVES DE LA MANCHURIE ET DE LA MONGOLIE ORIENTALES: Bull. Geol. Soc. China, v. 8, no. 1.

15. Tomita, Toru., 1932., GEOLOGICAL AND PETROLOGICAL STUDY OF DOGO, OKI. PART 17: Jour. Geol. Soc. Tokyo. v. 39, no. 464, p. 197-218. [Japanese]

16. ______________, 1933., OLIVINE-TRACHY-ANDESITIC BASALT FROM HSUEH-HUASHAN HILL, CHINGHSING DISTRICT, NORTH CHINA: Jour. Shanghai Sci. Inst., Sect. II, no. 1.

17. Sato, S., 1933., GEOLOGY AND PETROGRAPHY OF JEHOL. Report of the first scientific expedition to Manchoukuo, Section II, Part III, 208 pages. [Japanese]

18. Yeh, L. F. and Yu, T. Y., 1934. GEOLOGICAL HISTORY OF THE VOLCANIC ROCKS BETWEEN CHEN-CHIANG AND NANKING: Bull. Academia Sinica, ser. B., no. 1. [Chinese]

19. Ogura, T., and others., 1936., GEOLOGICAL REPORT OF THE SU-TA-LIEN-SHAN VOLCANO OF LUNGKIANG PROVINCE. Report volcanology of Manchoukuo, no. 1. [Japanese].

20. Ogura, T., 1936., SHIHLUNITE, A NEW ROCK TYPE OF ALKALI-BASALT, FROM THE VOLCANOES OF WUTALIEN-CHIH DISTRICT, LUNGCHIANG PROVINCE, NORTH MANCHURIA. Jour. Geol. Soc. Tokyo. v. 43, no. 510, p. 191. [Japanese]

21. Ogura, T., and others., 1938., GEOLOGICAL REPORT OF THE ER-K'E-SHAN VOLCANO OF LUNGKIANG PROVINCE: Report Volcanology of Manchoukuo no. 2, Ryojun College of Engineering. [Japanese]

22. ______________, 1939. GEOLOGICAL REPORT OF THE CH'I-HSIN-SHAN VOLCANO OF SOUTHERN KHINGAN AND LIAONING PROVINCE: Report Volcanology of Manchoukuo no. 3, Ryojun College of Engineering. [Japanese]

23. Ichimura, T., 1929., BRIEF NOTES ON THE ALKALINE ROCKS OF TAIWAN. Trans. Nat. Hist. Soc. Taiwan, XIX, no. 103.

24. ______________, 1943., ZIRCON AND CORUNDUM DEPOSITS OF MA-WU-TU AND MA-FU OF HSIN-CHU, TAIWAN: Science abstract, ser. 3, v. 1, no. 1, Taiwan University. [Japanese]

25. ______________, 1947., SOME BASALTS OF HAINAN ISLAND: Acta Geologica Taiwanica ser. 1, v. 1, no. 2, Taiwan University. [Chinese]

26. Cheng, Y. C., and Shen, Y. H., 1948. THE TERTIARY VOLCANIC ROCKS OF FANGSHAN, KIANGNING, KIANGAU: Bull. Geol. Soc. China, v. 28, nos. 3-4.

27. Ye, T. P., 1949., PRELIMINARY OBSERVATION OF THE ALKAL.-BASALT OF TS'AO-LING OF HSIN-CHU, TAIWAN: Geol. Notes Geol. Soc. China, v. 14, p. 176. [Chinese]

28. Harumoto, A., 1949., THE NEPHELINE BASALT OF T'ANG-SHAN OF CHI-HSIA-HSIEN, SHANTUNG: Earth Science, v. 1, no. 1. [Japanese]

29. Ichimura, T., 1950., A BRIEF GEOLOGICAL NOTE ON THE KUANYIN VOLCANO, TAIWAN. Jour. Geol. Soc. Japan, 56, 493.

30. Shen, Y. H., 1951., TERTIARY VOLCANICS OF CHIHSHAN, CHUJUNG, KIANGSU: Bull. Geol. Soc. China, v. 31.

31. Shen, Y. H., and Pan, C. H., 1951., THE TERTIARY BASALTS OF SHE-WU-SHAN, CHÜ-JUNG, KIANGSU: Geol. Notes Geol. Soc. China, v. 16, no. 2. [Chinese].

32. Shen, Y. H., 1951., THE TERTIARY VOLCANIC ROCKS OF CHU-T'OU-SHAN, P'U-CHEN, KIANG-P'U, KIANGSU: Scientific China, v. 2, no. 4. [Chinese]

33. Shukusuke Kozu and Kunikatsu Seto, 1922., ON ALKALINE ROCKS FROM CHOSEN. Jour. Geol. Soc. Tokyo, v. 29, no. 345, p. 211-218. [Japanese]

34. Yamanari, B., 1927., ON THE HAKUTO-ITE: Jour. Geol. Soc. Tokyo. v. 34, no. 410, p. 474-478.

35. Zavaritsky, A. N., 1936., LAVY VULK-ANOV V OKRESTNOSTYAKH MERGEN-YA [LAVAS OF VOLCANOES IN THE VICINITY OF MERGEN]: Doklady, Akad. Nauk SSSR, t. 1, no. 9.

36. Ogura, T., 1941., MINERALOGY AND CHEMICAL COMPOSITION OF THE VOLCANIC ROCKS OF MANCHURIA: Jour. Geol. Soc. Japan, v. 48, no. 570, p. 109-110. [Japanese]

37. Yagi, K., 1949., PETROLOGICAL NOTE ON THE OLIVINE TRACHYBASALT FROM WEI-TSCHOU ISLAND, SOUTH CHINA SEA. Proc. 7th Pacific Sci. Cong. Pacific Sci. Assoc.

38. Nemoto, T. 1935., THE VOLCANIC ROCKS OF PAI-T'OU-SHAN: Jour. Geol. Soc. Japan, v. 42, no. 501, p. 306-309. [Japanese].

39. Huang, T. K., 1945., ON MAJOR TEC-TONIC FORMS OF CHINA: Geol. Surv. China Mem., Ser. A, no. 20.

40. Sinitsin, V. M., 1954., OUTLINE OF THE GEOTECTONICS OF CHINA. Acta Geol. Sinica, v. 34, no. 3. [Chinese]

41. Nockolds, S. R., 1954., AVERAGE CHEMICAL COMPOSITION OF SOME IGNEOUS ROCKS. Bull. Geol. Soc. America, v. 65, p. 1007-1032.

42. Benson, W. N., 1942., THE BASIC IGNEOUS ROCKS OF EASTERN OTAGO AND THEIR TECTONIC ENVIRONMENT: Royal Soc. Newzealand Trans., 72, 113. nos. 2-11, ref. Turner and Verhoogen (1951).

43. Benson, W. N., and Turner, F. J., 1939., MINERALOGICAL NOTES FROM THE UNIVERSITY OF OTAGO. No. 2. Op. Cit., v. 69, Pt. 1, p. 71, nos. 26 and 30.

44. Holmes, A., and Harwood, H. F., 1937. THE PETROLOGY OF THE VOLCANIC AREA OF BUFUMLIRA, UGANDA.

45. Tomita, T., 1935., ON THE CHEMICAL COMPOSITION OF THE CENOZOIC ALKALINE SUITS OF THE CIRCUM-JAPAN SEA REGION: Jour. Shanghai Sci. Inst., Sect. II, v. 1, no. 5.

46. Benson, W. N., 1941., CENOZOIC PETROGRAPHIC PROVINCES IN NEW ZEALAND AND THEIR RESIDUAL MAG-MAS: Am. Jour. Sci., v. 239, no. 8. - ref. Green and Poldervaart (1955).

47. Yagi, K., 1953., PETROCHEMICAL STUDIES ON THE ALKALIC ROCKS OF THE MOROTU DISTRICT SAKHALIN: Bull. Geol. Soc. America, v. 34, p. 769-810.

48. Macdonald, G. A., 1949., HAWAIIAN PETROGRAPHIC PROVINCE: Bull. Geol. Soc. America, v. 60, p. 1541-1595.

49. Green, J., and Poldervaart, A., 1955. SOME BASALTIC PROVINCES: Geo-chimica et Cosmochimica Acta, v. 7, nos. 3/4.

50. Willems, H. W. V., 1945., ON THE MAG-MATIC PROVINCES IN THE NETHER-LANDS EAST INDES: Geol. mijnb. Gen. Verh., Geol., v. 12.

51. Iwasaki, I., 1937., GEOCHEMICAL INVESTIGATIONS OF VOLCANOES IN JAPAN, VII. AVERAGE CHEMICAL COMPOSITION OF VOLCANIC ROCKS IN JAPAN: Jour. Japan Chem. Soc., v. 58, no. 4.

52. Tyrrell, G. W., and Sandford, K. S., 1933., GEOLOGY AND PETROLOGY OF THE DOLERETES OF SPITZBERGEN: Proc. Roy. Surv. Edinburgh., v. 53, Pt. 3.

53. Walker, F., and Poldervaart, A., 1949., KAROO DOLERITE OF THE UNION OF SOUTH AFRICA: Bull. Geol. Soc. America, v. 60, p. 591-701.

54. Washington, H. S., 1932., DECCAN TRAPS AND OTHER PLATEAU BASALTS: Bull. Geol. Soc. America, v. 33, p. 765-804.

55. Holmes, A., and Harwood, H. F., 1929., THE THOLEIITIC DIKES OF THE NORTH OF ENGLAND: Mineral. Mag., v. 22, p. 1-52.

56. Tomita, Toru., 1937., ON THE CHEMICAL COMPOSITIONS OF MONOCLINIC PYROX-ENES, AMPHIBOLES, AND MICAS IN IGNEOUS ROCKS, PART 2: Jour. Geol. Soc. Japan, v. 44, no. 530, p. 947-980. [Japanese]

57. Zavaritsky, A. N., 1950., VVEDENIE V PETROKHIMIYU IZVERZHENIKH GOR-NYKH POROD [INTRODUCTION TO THE PETROCHEMISTRY OF IGNEOUS ROCKS]: Akad. Nauk SSSR.

58. Kuno, K., 1949., PLATEAU BASALT LAVAS OF EASTERN MANCHURIA: Proc. of the 7th. Pacific Sci. Cong. of Pacific. Sci. Assoc.

59. Mountain, E. D., 1925., POTASH OLIGOCLASE FROM MOUNT EREBUS, ANTARCTIC, AND ANORTHOCLASE FROM MT. KENYA, EAST AFRICA. Minerolog. Mag., v. 20, p. 331-345.

60. Macdonald, G. A., 1942., POTASH OLIGOCLASE IN HAWAIIAN LAVAS. American mineralogist, v. 27, p. 793-800.

61. Kuno, H., 1950., PETROLOGY OF HAKONE VOLCANO AND THE ADJACENT AREA, JAPAN: Geol. Soc. Amer. Bull., v. 61, p. 957-1020.

62. Yamada, S., 1930., ON THE AVERAGE CHEMICAL COMPOSITIONS OF SOME TYPES OF JAPANESE EFFUSIVE ROCKS: Jour. Geol. Soc. Japan, v. 37, p. 1-4.

63. Peacock, M. A., 1931., CLASSIFICATION OF IGNEOUS ROCKS SERIES: Jour. Geol., v. 39, p-54-67.

64. Tsuboi, S., and Kuno, H., 1932., ON THE SO-CALLED "PYROXENE ANDESITE", THE COMMONEST VOLCANIC ROCK IN JAPAN: Bull. Soc. Japan, v. 1, p. 21.

65. Katsui, Z. Yoshio., 1954., CHEMICAL COMPOSITION OF THE LAVAS FROM THE VOLCANIC ZONE, JAPAN; Jour. Geol. Soc. Japan, v. 60, no. 704, p. 185-191. [Japanese]

66. Holmes, A., 1920., PETROGRAPHIC METHOD.

67. Kennedy, W. Q., 1933., TRENDS OF DIFFERENTIATION IN BASALTIC MAGMAS: Amer. Jour. Sci. v. 25, no. 147.

68. Hess, H. H., 1941. PYROXENES OF COMMON MAFIC MAGMAS: Amer. mineralogist, v. 26, p. 515-535, 573-594.

69. Edward A. B., 1942., DIFFERENTIATION OF THE DOLERITES OF TASMANIA II: Jour. Geol., v. 50, p. 579-610.

70. Kennedy, W. Q., and Anderson, E. M., 1938., CRUSTAL LAYERS AND THE ORIGIN OF MAGMAS: Bull. volcanologique, Ser. 2, 3, 23-82.

71. Tilley, C. E., 1950., SOME ASPECTS OF MAGMATIC EVOLUTION: Geol. Soc. London, Quart. Jour., v. 91, p. 37-67.

72. Walker, F., and Davidson, C. F., 1936., A CONTRIBUTION TO THE GEOLOGY OF THE FAEROES: Royal. Soc. Edinburgh Trans., v. 58.

73. West, W. D., 1932., ORIGIN OF ULTRA-BASIC LAVAS, KATHIAWAR, BOMBAY: Rec. Geol. Surv. India, v. 66, Part I.

74. Kuno, Hisashi., 1937., FRACTIONAL CRYSTALLIZATION OF BASALTIC MAGMAS. Jour. Geol. Soc. Japan, v. 44, no. 523, p. 262-284. [Japanese]

75. Barth, T. F. W., 1942., LAVAS OF GOUGH ISLAND: Sci. Results Norwegian Antarctic Expedition, 1927-1928, no. 20 - ref. Turner, F. F. and J. Verhoogen (1951)

76. Gorai, Masao., 1940., ON GENESIS OF ALKALI BASALTS OF WUTALIENCHIH VOLCANO, NORTH MANCHURIA (PART I): Jour. Geol. Soc. Japan, v. 47, no. 566, p. 457-467. [Japanese]

77. Knopf, A., 1938., PARTIAL FUSION OF GRANODIORITE BY INTRUSIVE BASALT, OWENS VALLEY, CALIFORNIA: Amer. Jour. Sci., v. 34, no. 215.

78. Goranson, R. W., 1932., SOME NOTES ON THE MELTING OF GRANITES: Amer. Jour. Sci., v. 23.

79. Winkler, A., 1914. DIE TERTIAREN ERUPTIVA AM OSTRAND DER ALPEN: Zeit Vulkanologie I., S. 182.

80. Barth, T. F. W., 1939., DIE ENTSTEHUNG DER GESTEINE (Barth, Correns, Eskola), Springer, Berlin.

81. Harker, A., 1909., THE NATURAL HISTORY OF IGNEOUS ROCKS. Macmillan, London.

82. Tyrrell, G. W., 1929., PRINCIPLES OF PETROLOGY. Dutton, N. Y.

83. Kent, P. E., 1944., THE AGE AND TECTONIC RELATIONSHIP OF EAST AFRICA VOLCANIC ROCKS: Geol. Mag., v. 87, p. 15-25.

84. Benson, W. N., 1942., THE BASIC IGNEOUS ROCK OF EASTERN OTAGO AND THEIR TECTONIC ENVIRONMENT: Roy. Soc.

New Zealand Trans. v. 72.

85. Brouwer, H. A., 1946., THE ASSOCIATION OF ALKALI ROCKS AND METAMORPHIC LIMESTONE IN A BLOCK EJECTED BY THE VOLCANO MERAPI (JAVA): K. Akad. Westensch. Amsterdam verh., v. 48 - ref. Turner and Verhoogen (1951).

86. ______________ 1939., LEUCITE ROCKS OF ACTIVE VOLCANO BATOE TARA (MALAY ARCHIPELAGO): K. Akad. Westensch., v. 17(1), p. 23-29.

87. Daly, R. A., 1944-1946., VOLCANISM AND PETROGENESIS AS ILLUSTRATED IN THE HAWAIIAN ISLANDS: Geol. Soc. Amer. Bull., v. 55, d. 57.

88. Bullen, K. E., 1947., AN INTRODUCTION TO THE THEORY OF THE SEISMOLOGY. Cambridge Press.

89. Zavaritsky, A. N., 1946., NEKOTORYE FAKTY, KOTORYE NADO UCHITYVAT, PRI TEKTONICHESKIKH POSTROYENIYAKH. [CERTAIN FACTS WHICH MUST BE CONSIDERED IN TECTONIC SYNTHESIS] Izvestiya Akad. Nauk. SSSR, Seriya Geologicheskaya.

90. Bowen, N. L., 1928., THE EVOLUTION OF THE IGNEOUS ROCKS, pp. 315-320. Princeton, N. Y.

91. Turner, F. J., and Verhoogen, J., 1951., IGNEOUS AND METAMORPHIC PETROLOGY.

92. Kuno, Hisashi., 1940., ON A PIGEONITE-QUARTZ-DIORITE BLOCK EJECTED FROM HAKONE VOLCANO. Jour. Geol. Soc. Japan, v. 47, no. 560, p. 175-179. [Japanese].

THE CHEMICAL COMPOSITION OF METEORITES[1]

by

A. A. Yavnel and M. I. Dyakonova

• *translated by Royer and Roger, Inc.* •

ABSTRACT

At present, investigations on the chemical composition of meteoritic matter are being made in two directions: 1) the determination of the main constituents of meteorites of different classes. (A generalization of these data led to the classification of meteorites depending on their chemical composition); 2) the determination of all the element contents including small admixtures in meteoritic matter according to their phases: metallic, silicate, and also in accessory minerals.

A review of all data on the composition of meteorites ensures the systematic study of their mineral content, structure and other properties and makes possible a closer approach to the solution of their origin.

As a result of a critical review of existing general investigations and separate data concerning the contents of the basic constituents of meteorites, the composition of each subclass divided into families according to groups is given in the tables.

Changes in the composition of meteorites of each group while passing from one subclass to another are clearly seen in the tables, and this allows an opinion to be formed on the laminated planetary bodies from which the meteorites were formed.

The contents of all the chemical elements found in meteoritic matter are given in tables. The results of recently published works have been taken into account, and old data have been reconsidered. -- from English supplement to Meteoritika.

***

The determination of the chemical composition of meteorites is one of the foremost tasks in the study of this cosmic substance.

As it stands now, the problem is twofold. The first task is the analysis of meteorites of different classes (iron, stony-iron, stone) to determine their main components. Generalization from these data has led to a classification of meteorites by their chemical composition [1], wherein each analysed meteorite may be assigned to some family or type.

The next task is the determination of the content for all the elements (including the minor admixtures) in the meteorite substance. The results of such a study reveal the distribution of chemical elements in the principal phases of the meteorite substance and, in greater detail, in individual minerals, including the accessory ones, which occur in these phases.

By the phases of the meteorite substance is meant silicate and metal components; these enter in various proportions into the composition of all meteorites, from the calcium-rich achondrites, almost lacking in metal, to the siderites which are iron meteorites. Among the accessory minerals are troilite (FeS), schreibersite [$(Fe, Ni)_3P$], chromite [$(Fe, Mg) Cr_2O_4$], daubréelite [$FeCr_2S_4$] and others, which often appear in meteorites as isolated inclusions. It should be noted that the term silicate and metal phases, as used in the literature, is understood as a rule to mean only the silicate and metal fractions of meteorites in the individual classes, excluding the accessory minerals.

Cumulative data on chemical composition of meteorites provides the key to an orderly study of mineral composition, structure and various properties of meteorite substance, from which in turn one may approach the problem of the origin of meteorites. In this connection, systematization of factual information on the composition of meteorite substance is of great importance.

Accordingly, one may begin with the content of principal components of meteorites.

CONTENT OF THE PRINCIPAL COMPONENTS OF METEORITES

Data are plentiful on this subject, because most of the analytical work has been devoted to determination of these principal components in meteorites. At the same time, not all of these data may be drawn upon safely; this applies especially to those from the last century

---

[1] Translated from Khimichesky sostav meteoritov: Meteoritika, Akademiya Nauk SSSR, Komitet po meteoritam, no. 15, 1958, p. 136-151.

when inadequate research methods led to considerable errors.

Nevertheless, the data available make it possible to subdivide the meteorites of all three classes-(iron, stony-iron, and stone) into the following definite subclasses with differing ratios of silicate to metal phases: 1) siderites; 2) lithosiderites (pallasites); 3) siderolites (mesosiderites); 4) chondrites; 5) achondrites poor in calcium; and 6) achondrites rich in calcium. In addition, the meteorites of all subclasses are grouped into families in which these phases have different compositions [1].

It is suitable, therefore, to present some of the data on meteorite composition for each subclass, subdivided by groups into families.

The compositions for meteorites of different classes are best seen from total analyses; these indicate compositions of individual parts and accessory minerals, and the relationships between them. Some authors give only the compositions for principal fractions of the meteorites of a given class, such as that of the metal in iron meteorites or of the silicate in stone meteorites, often without specifying this fact. This circumstance has been taken into consideration in this paper.

The tables given, list the average concentrations of each element, as obtained graphically from histograms. This method of averaging reveals easily the chance deviations and gives better results than the arithmetical mean. The figures have been rounded off according to the precision of their determinations.

The ranges in content for some of the component are given in brackets, in Tables 1 through 7; figures in parentheses need verification.

Average values in the last column of each table, although they have physical significance, characterize broadly the composition of meteorites in that subclass. Because the genetic connection between meteorite families of the different subclasses comprise the same group, average total composition of the individual groups is of great interest. This, however, implies that the ratio is known for numbers of meteorites in the various classes, which involves some difficulty.

Changes in composition of each group with the change from one subclass to another, can be followed in the tables. On this basis, one can guess at the "cross-sections" of stratified planetary bodies from which meteorites were formed.

Composition of the iron meteorites, which appear to have made up the cores of those bodies, will begin the study.

Iron Meteorites (Siderites)

Literature on the composition of iron meteorites is scant. It includes the 1907 summary by Farrington [2] of analyses for 318 meteorites; that of P. N. Chirvinsky, in 1922 [3], for 360 analyses; that of J. and W. Noddack, in 1930 [4], for 16 meteorites, and that of Brown and Patterson, in 1947 [5], for 220 meteorites. All of these papers give the average content for iron meteorites and, differ little from each other in their results.

The figures given by these authors have been used in most other works; at times, modified to have their sum add up to 100 percent, or in various combinations.

There are, in addition, papers by P. N. Chirvinsky (3) and Buddhue, [6], which give the compositions of iron meteorites of different structural types. It should be noted that these data are tentative as is differentiation of iron meteorites by their structure. These data reflect only the general connection between composition and structure of iron meteorites and do not in any way differentiate them by their chemical composition. A conspicuous feature is excessively high nickel content in the nickel-poor ataxites; this is a substantial error of these two works. Buddhue also mentions "average" composition of the nickel-iron in meteorites of the different classes: i. e. iron, stony-iron, and stone. This has been taken erroneously by some authors to be the average composition for iron meteorites.

The basis for all summaries of the iron meteorites has been not their total composition, but their nickel-iron composition; inasmuch as accessory mineral inclusions usually do not seem to be part of analyzed samples. This is proved by the lack of sulfur in most analyses. It follows that the presence of various amounts of sulfur in some meteorite analyses results from different degrees of contamination of the samples by the iron sulfide, troilite. The same is true for phosphorus content in iron meteorites. The phosphorus usually cited in the analyses (in the amounts of 0. 1 to 0. 3 percent) is present in iron meteorites principally as microcrystals of rhabdite, an iron-nickel phosphide, precipitated from a supersaturated solid solution of phosphorus in a Fe-Ni alloy. The larger amount of phosphorus in some meteorites indicates the presence in analyzed samples of admixtures of another nickel-iron phosphide: coarse inclusions of schreibersite, primary crystals of $(Fe, Ni)_3P$; with a different Fe/Ni ratio from that in rhabdite, secondary crystals of $(Fe, Ni)_3P$.

Troilite and schreibersite usually are constant admixtures in iron meteorites and should be fully accounted for. P. N. Chirvinsky [7] properly took this circumstance into account

in the case of troilite by estimating the average amount of the latter to be 1.4 percent by weight in six iron meteorites, from photographs of their structure. The amount of schreibersite inclusions in iron meteorites also reaches several percent, but has not been determined with any degree of precision. Daly's figure [8] of 1.12 percent for schreibersite in iron meteorites, obtained on the basis of 0.17 percent concentration of phosphorus, actually is valid only for rhabdite.

Because of this circumstance, the table in this paper, (based on similar analyses of iron meteorites) also reflects only nickel-iron composition in meteorites of that class. When additional reliable data on troilite and schreibersite content of iron meteorites become available, the table will have to be corrected accordingly.

There are about 560 known iron meteorites, most of which have been analysed. The latest analyses of 373 meteorites were used in the compilation of the table. No special selectivity was exercised in these analyses; it was believed that the analyses errors for iron meteorites (principally for Ni determination) were not so much the result of shortcomings in the analytical method as of improper selection of the average sample, because of lack of uniformity in composition of iron meteorites. This is true mostly for octahedrites; their structural components kamacite and taenite, with their different compositions, are unevenly distributed.

Inasmuch as errors in the selection of samples are not systematic, incidental deviations of the results in one direction or another are mutually compensated when there is a large number of analyses, and, do not affect determination of the averages. Apparently, these errors merely broaden the distribution curve somewhat, without displacing its maximum.

Table 1 below shows the composition of nickel-iron in iron meteorites.

which had been dissolved previously in the nickel-iron.

Stony-iron Meteorites

This class of meteorites is divided into two subclasses: lithosiderites and siderites.

Lithosiderites

The lithosiderites are represented chiefly by pallasites, now 39 in number. P. N. Chirvinsky has studied their average composition for many years and has published several summaries of the available data: in 1917 [10]; on analysis results of 15 pallasites in 1918 [11]; and, on 18 pallasites in 1949 [12]. Buddhue [6] has determined the average composition for the metal fraction of 14 pallasites.

Chirvinsky's summaries give the average composition of pallasites by weight. Since no relationship between the composition of individual pallasites (as well as meteorites of other classes) and their mass has been observed, however, it is considered more correct not to consider weight in computing average composition for meteorites of the same subclass. Otherwise, the fall of a single meteorite with a large mass may modify substantially the results of averaging.

For comparison, Table 2 has been compiled from analyses of 23 pallasites. The last column gives the composition of lodranite, which differs from pallasites in its composition and structure.

The pallasites of each group differ in both composition and in amounts of principal components: olivine and nickel-iron.

There are no summaries on the composition of mesosiderites, excepting the average of two analyses computed by Daly [18]. Buddhue [6] cites the composition of only a single fraction, that of nickel-iron, for nine mesosiderites.

TABLE 1. Iron meteorites (nickel-iron), percent by weight

Composition	Group I	Group II	Group III	Group IV	Group V	Average
	Number of meteorites					
	77	246	43	5	2	373
Fe	93.5	91	85	68	38	90.5
Ni	5.6[4÷7]	8[5.5÷11]	14[8÷20]	30[20÷40]	60[<40]	8.7
Co	0.5	0.55	0.7	1.0	(0.7)	0.56
Cu	0.03	0.02	0.03	-	(0.30)	0.02
P	0.25	0.20	0.10	0.10	0.10	0.20
S	0.00	0.00	0.00	0.00	-	0.00
C	0.04	0.10	0.02	-	-	0.08
Σ	99.9	99.9	99.9	99.1	99.1	100.0

This table shows a considerable increase in the nickel content from Group I to Group V, accompanied by an increase in cobalt concentration and decrease in the amount of phosphorus,

Table 3 shows the compositions of mesosiderites belonging to two families, from published results of nine analyses. Also, it gives the compositions of two individual stony-iron

TABLE 2. Lithosiderites, percent by weight

Composition	Pallasites			Lodranite (Lodran)
	Group II	Group III	Average	
	Number of meteorites			
	20	3	23	
SiO_2	17	24	18	39
MgO	20	27	21	23
FeO	5.5	12	6.5	8.5
Al_2O_3	0.1	0.3	0.12	0.4
Na_2O	0.03*	0.03*	0.03	-
K_2O	0.005*	0.008*	0.006	-
MnO	0.1	0.2	0.1	-
Σ silicates	43	65	46	≈ 70
Fe	51	29	48	27
Ni	5.1	5.2	5.1	2.3
Co	0.3	0.3	0.3	-
Cu	0.03	0.03	0.03	-
P	0.06	0.02	0.05	-
Σ metals	57	35	54	≈ 30

* G. Edwards, Geochimica et Cosmochimica Acta, 8, no. 5/6, 285, 1955.

TABLE 3. Siderolites, percent by weight

Composition	Mesosiderites			Siderophyre (Steinbach)	Grahamite (Nechayevo)
	Group I	Group II	Average		
	Number of meteorites				
	1	8	9		
SiO_2	14	25	24	24.7	9.5
MgO	10	14	13.5	7.6	4
FeO	2	8	7.3	3.2	8
Al_2O_3	0.8	4	3.7	0.6	0.2
CaO	1.2	4	3.7	0.6	2.5
Na_2O	-	0.2	0.2	0.4	0.3
Σ silicates	30	55	52	37.1	≈ 25
Fe	65	40	43	50.2	72+0.4*
Ni	4	4.5	4.5	5.4	2+0.15*
Co	0.4	0.2	0.2	0.1	-
P	-	0.07	0.07	0.08	0.1
Σ metals	70	45	48	55.8	≈ 75

* Nickel-iron in small inclusions in the silicate.

meteorites, siderophyre, and grahamite.

Because definite data is lacking on amounts of sulfur and phosphorus in pallasites and mesosiderites, Tables 2 and 3 do not give the content of troilite and schreibersite.

Stony Meteorites

Average composition for meteorites of this class usually is taken from the summary by Merrill [13], 1909, of the analyses of 99 stony meteorites; from Farrington [14], 1911, on 125 meteorites; Merrill [15], 1916, on 53 meteorites; and Merrill [16], 1930, on 63 meteorites. Average composition for the non-magnetic fraction of 42 stony meteorites was determined by J. and W. Noddack [4], in 1930. In addition, there are papers by Brown and Patterson [5, 17], 1947, giving average composition for silicate and iron fractions of 107 stony meteorites.

The discrepancies between these summaries have two causes: The first is lack of precision in analyses of individual meteorites, which were used by some authors in their tabulations. The other is the fact that stony meteorites belong to three subclasses differing considerably in their chemical compositions: chondrites, calcium-poor achondrites, and calcium-rich achondrites. Consequently, the computed average compositions of stony meteorites which have been used for the different calculations depend also on the ratio of the number of meteorites in each subclass.

The 1953 paper by Urey and Craig [18] compares favorably with the earlier ones, in that it cites the most reliable analysis results for stony meteorites and differentiates the meteorites by types corresponding to the previously named subclasses.

Composition of the stony meteorites will be

discussed individually for each subclass.

Chondrites

The only summary of average composition for chondrites is found in the paper by Urey and Craig [18], which compiles analyses of 93 meteorites in this subclass, out of the 800 that are known. Composition of the metal fraction for 41 chondrites has been published by Buddhue [6].

In Daly's 1943 data [8], average composition of stony meteorites (after Merrill [15]) including achondrites, is incorrectly given as composition of the chondrites.

The basis of the present summary is data from Urey and Craig, supplemented by new analysis results for chondrites. A place of their own among the chondrites is occupied by carbonaceous chondrites with their higher carbon, water, and sulfur content. They may be divided by these criteria into three types. Composition of the carbonaceous chondrites is after Wiik [19]. Altogether, a total of 130 chondrites have been used. Table 4 gives the composition of chondrites belonging to definite groups.

Composition of the chondrites in different groups changes regularly from one family to another (Prior's "Group Rule").

Achondrites poor in calcium

A total of 26 calcium-poor achondrites are known at the present time. Average chemical composition for 13 achondrites of this subclass is given by Urey and Craig [18].

Table 5 gives the composition of 18 achondrites, subdivided into types.

Achondrites rich in calcium

This subclass includes 40 meteorites. Average composition of 18 eucrites and howardites, which make up the bulk of the calcium-rich achondrites, was given by Chirvinsky in 1941 [20]. In 1943, Daly [8] computed average composition for four achondrites of this type. The 1953 summary by Urey and Craig [18] contains the average composition for 25 calcium-rich achondrites.

It should be noted that Washington's figures [21], cited by Daly, on average composition for achondrites, refer to achondrites of both subclasses; those rich and poor in calcium.

Table 6 presents the composition for 25 calcium-rich achondrites, subdivided into five types.

TABLE 4. Chondrite, percent by weight

Composition	Group I	Group II	Group III	Group IV	Carbon, type			Average 130 meteorites
					Felix	Migei	Orgueil	
	Number of meteorites				Number of meteorites			
	6	45	56	7	4	8	4	
SiO_2	41.5	36.0	39.5	39.5	33.7	27.6	22.6	37.0
MgO	23.2	23.2	24.8	25.2	23.7	19.3	15.2	23.6
FeO	1.0	11.0	14.2	20.5	24.3	20.8	10.1	13.5
	[0÷3]	[5÷15]	[10÷20]	[17÷26]				
Al_2O_3	2.2	2.3	2.6	2.2	2.6	2.3	1.7	2.4
CaO	1.2	1.8	2.0	2.0	2.3	2.0	1.5	1.9
Na_2O	1.0	0.93 1/	0.93 1/	0.9	0.5 1/	0.6 1/	0.8 1/	0.9
K_2O	(0.2)	0.10 1,2/	0.11 1,2/	(0.25)	0.05 1/	0.05 1/	0.07 1/	0.11
Cr_2O_3	0.25	0.25	0.40	0.35	0.5	0.4	0.3	0.34
MnO	0.1	0.25	0.25	0.20	0.2	0.2	0.2	0.23
TiO_2	0.12	0.11	0.14	0.17	0.1	0.1	0.07	0.12
P_2O_5	0.06	0.20	0.26	0.20	0.3	0.3	0.3	0.23
C					0.4	2.3	3.5	0.22
H_2O	0.2	0.25	0.25	0.3	0.9	13.0	20.1	1.5
Σ silicates	71.0	76.2	85.5	91.7	89.5	88.9	76.4	82.0
Fe	24.2	16.7	7.3	2.0	2.8	(0)	(0)	11.2
Ni	1.69	1.66	1.18	0.90	1.4	1.5	0.9	1.4
Co	0.12	0.10	0.05	0.05	0.08	0.07	0.05	0.07
Σ metals	26.0	18.5	8.5	3.0	4.3			12.7
	[22÷28]	[12÷25]	[5÷12]	[1÷6]				
Fe	4.4	3.4	4.0	3.8	3.7	5.5	10.5	4.0
S	2.5	2.0	2.3	2.2	2.1	3.1	6.0	2.3
Σ sulfides	6.9	5.4	6.3	6.0	5.8	8.6	16.5	6.3

[1] G. Edwards, H. Urey. Geochimica et Cosmochimica Acta, 7, no. 3/4, 154--168 (1955). G. Edwards, Geochimica et Cosmochimica Acta, 8, no. 5/6, 285--294 (1955).
[2] W. Pinson, L. Ahrens, M. Frank. Geochimica et Cosmochimica Acta, 4, no. 5, 251 (1953).

TABLE 5. Achondrites poor in calcium, percent by weight

Composition	Group I: Obrites (bustites, chladnites) 5 meteorites	Ureilites 2 meteorites	Rodites, diogenites 7 meteorites	Group IV: Amphoterites 3 meteorites	Chassignites (Chassigny)	Average 17 meteorites
SiO_2	55	40	53	40	(37.2)	49
MgO	36.5	37	26.5	26	(33.6)	30.5
FeO	1[0÷2]	13	17[13÷21]	20[18÷22]	(26.7)	12
Al_2O_3	0.7	0.6	1.5	1.8	-	1.2
CaO	1.2	1.0	1.4	1.6	-	1.4
Na_2O	0.3*	0.05*	0.004*	0.9*	-	0.25
K_2O	0.1*	0.007*	0.001*	0.1*	(0.6)	0.05
Cr_2O_3	0.1	1	1.2	0.5	(0.7)	0.8
MnO	0.2	0.4	0.3	0.3	(0.4)	0.3
TiO_2	0.06	-	0.2	-	-	0.1
P_2O_5	0.2	-	0.03	-	-	0.1
Σ silicates	95	93	101	91	99.4	96
Fe	3[0.2÷8]	6.8	0.8	1.9	-	2.3
Ni	0.02	0.2	0.03	0.9	-	0.2
Co	-	-	-	0.05	-	
Σ metals	(3)	7.0	0.83	2.85		2.5
Fe	0.8	0.3	0.6	3.9	-	1.2
S	0.5	0.2	0.3	2.2	-	0.6
Σ sulfides	1.3	0.5	0.9	6.1		1.8

TABLE 6. Achondrites rich in calcium, percent by weight

Composition	Eucrites, howardites 13 meteorites	Howardites, eucrites 8 meteorites	Shergottites (Shergotty)	Angrites (Angra dos Reis)	Nakhlites (Nakhla)	Serra de Mage	Average 25 meteorites
SiO_2	49	51	50.2	43.9	49.0	43.4	49
MgO	8	16	10.0	10.0	12.0	3.2	11
FeO	18	16	21.8	8.6	20.7	6.6	17
Al_2O_3	13	9	5.9	8.7	1.7	27.2	11
CaO	10	7	10.4	24.5	15.2	14.5	10
Na_2O	0.5*	0.2*	(1.3)	(0.3)	0.6*	(1.6)	(0.5)
K_2O	0.06*	0.02*	(0.6)	(0.2)	0.12*	(0.2)	(0.09)
Cr_2O_3	0.4	0.5	-	-	0.3	0.3	0.4
MnO	0.4	0.4	-	-	0.1	0.6	0.4
TiO_2	0.4	0.1	-	2.4	0.4	-	0.4
P_2O_5	0.1	0.1	-	0.1	-	-	0.1
Σ silicates	100	100	100.2	98.7	100.2	97.6	100
Fe metal	1.2	0.4	-	-	-	-	0.9
Fe	0.27	0.50	-	0.8	0.10	0.07	0.35
S	0.15	0.29	-	0.5	0.06	0.04	0.25
Σ sulfides	0.42	0.79		1.3	0.16	0.11	0.60

* G. Edwards, and H. Urey, Geochimica et Cosmochimica Acta, 7, no. 3/4, 154-168, 1955; G. Edwards, Geochimica et Cosmochimica Acta, 8, no. 5/6, 285-294, 1955.

DISTRIBUTION OF ELEMENTS IN METEORITIC SUBSTANCE

Only a few authors have determined content of the various elements, including minor admixtures, in the meteoritic substance. One of the earliest papers on this subject was the 1930 study by J. and W. Noddack [4], on distribution of elements in the non-magnetic fraction of stony meteorites (silicate fraction and troilite), in the metallic fraction of iron meteorites, and in trolite.

This work was of great importance to the chemistry of meteorites, even though it was based on analyses for only three samples (mixtures) of the previously-named meteoritic fractions; this prevented the authors from discovering chance errors. These errors may be accounted for to a certain extent by contamination of iron meteorite samples with silicates, as suggested by the excessive amount of silicon

TABLE 7. Distribution of chemical elements in the substance of meteorites, percent by weight

Group	Elements	Silicate fraction of stony meteorites		Metal fraction of iron meteorites		Troilite		Schreibersite	Chromite
		After Brown [23]	This paper	After Brown [23]	This paper	After Brown [23]	This paper		
I	Li^{3}	$3x10^{-4}$	$3x10^{-4}$	-		-			
	Na^{11}	0.779	0.81	-		-			
	K^{19}	0.199	0.11	-		-			
	Rb^{37}	$4.5x10^{-4}$	$2-4x10^{-4}$	-		-			
	Cs^{55}	$1x10^{-5}$	$5x10^{-5}$	-		-			
	Fr^{87}	-							
	Cu^{29}	$1.6x10^{-4}$	?	0.031	0.015	0.420	⩽0.1	0.02	
	Ag^{47}	0		$3.3x10^{-4}$		$2.1x10^{-3}$			
	Au^{79}	0		$1.8x10^{-4}$		$4.5x10^{-5}$			
II	Be^{4}	$1x10^{-4}$		-		-			
	Mg^{12}	15.82	17.5	$3.2x10^{-2}$	$(<1x10^{-3})$	-	$1x10^{-3}$	$(1x10^{-3})$	6.0
	Ca^{20}	1.97	2.0	$5x10^{-2}$	?	-			
	Sr^{38}	$2.6x10^{-3}$	$1x10^{-3}$	-		-			
	Ba^{56}	$9x10^{-4}$	$4-8x10^{-4}$	-		-			
	Ra^{88}		$3x10^{-12}$		$5x10^{-12}$				
	Zn^{30}	$3.4x10^{-4}$		$1.15x10^{-2}$		0.152			
	Cd^{48}	$1.6x10^{-4}$		$8x10^{-4}$		$3x10^{-3}$			
	Hg^{80}	$1x10^{-6}$		-		$2x10^{-5}$			
III	Sc^{21}	$5.8x10^{-4}$	$6x10^{-4}$	-		-			
	Y^{39}	$6.6x10^{-4}$		-		-			
	La^{57}	$2.2x10^{-4}$		-		-			
	Ac^{89}	$2x10^{-15}$		-		-			
	B^{5}	$3x10^{-4}$		-		-			
	Al^{13}	1.74	1.9	$4x10^{-3}$	$(<1x10^{-3})$	-	$(1x10^{-3})$	$(1x10^{-3})$	$(3x10^{-3})$
	Ga^{31}	$5x10^{-5}$	$3x10^{-4}$	$5x10^{-3}$	$3.4x10^{-3}$	$5x10^{-5}$			
	In^{49}	$2.4x10^{-5}$		$1x10^{-4}$		$8x10^{-5}$			
	Tl^{81}	$1.5x10^{-5}$		-		$3x10^{-5}$			
IV	Ti^{22}	0.093	0.1	$1x10^{-2}$		-	$\sim 2x10^{-4}$		(0.04)
	Zr^{40}	$1x10^{-2}$	$3x10^{-3}$	$8x10^{-4}$		-			
	Hf^{72}	$1x10^{-4}$		-		-			
	C^{6}	0.04		0.11	0.08	-			
	Si^{14}	20.57	22.2	$4x10^{-3}$		-	(0.03)	(0.03)	(0.05)
	Ge^{32}	$1x10^{-3}$	$<1x10^{-3}$	$1.9x10^{-2}$	$1.1x10^{-2}$	$6x10^{-2}$	$1-3x10^{-2}$	$3x10^{-3}$	(0.01)
	Sn^{50}	$3x10^{-4}$	$<4x10^{-5}$	$7.7x10^{-3}$	$<0.5-10x10^{-4}$	0.16 (?)	$2x10^{-3}$	$2x10^{-3}$	
	Pb^{82}	$2x10^{-4}$	$7x10^{-5}$?	$6x10^{-3}$	$4x10^{-5}$	$2x10^{-3}$	$2x10^{-3}$		

V	V^{23} Nb^{41} Ta^{73} N^{7} p^{15} As^{33} Sb^{51} Bi^{83}	$9x10^{-3}$ $5x10^{-5}$ $3.8x10^{-5}$ $9x10^{-5}$ 0.158 $2x10^{-3}$ $1x10^{-5}$ -	• 0.1 $3x10^{-5}$ $1x10^{-6}$?	$6x10^{-4}$ $2x10^{-5}$ $6x10^{-6}$ - 0.22 $3.6x10^{-2}$ $2x10^{-4}$ $5x10^{-5}$	$6x10^{-5}$ 0.2 $6x10^{-4}$ $7x10^{-5}$	- - - - 0.31 0.10 $7.8x10^{-4}$ $2x10^{-4}$	~0.01 ? $1x10^{-3}$	(0.3) 15	
VI	Cr^{24} Mo^{42} W^{74} O^{8} S^{16} Se^{34} Te^{52} Po^{84}	0.345 $2.5x10^{-4}$ $1.8x10^{-3}$ 41.02 1.79 $1.3x10^{-3}$ -	0.3 $6x10^{-5}$ 44 ? $7x10^{-16}$	0.024 $1.66x10^{-3}$ $8.1x10^{-4}$ - $3.6x10^{-2}$ $3x10^{-4}$ -	$4x10^{-4}$ $2x10^{-3}$ 0	0.12 $1.1x10^{-3}$ - - 34.3 $1x10^{-2}$ $1.7x10^{-3}$	1÷2	0.01	45
VII	Mn^{25} Tc^{43} Re^{75} H^{1} F^{9} Cl^{17} Br^{35} I^{53} At^{85}	0.296 - - 0.063 $4x10^{-3}$ $9x10^{-2}$ $2.5x10^{-3}$ $1.26x10^{-4}$	0.2 0.03 0.01 $1x10^{-3}$	0.03 - $8.5x10^{-5}$ - - - $1x10^{-4}$ $6x10^{-5}$	$5x10^{-3}$ $1-3x10^{-3}$ 0.01 $1x10^{-4}$	0.046 - - - - - - -	0.04	$(1x10^{-3})$	(0.8)
VIII	Fe^{26} Co^{27} Ni^{28} Ru^{44} Rh^{45} Pd^{46} Os^{76} Ir^{77} Pt^{78}	15.64 0.0206 0.138 0 0 0 - 0 $8.3x10^{-6}$	12.0 0.00 0.00	90.78 0.63 8.59 $1.06x10^{-3}$ $4.1x10^{-4}$ $3.7x10^{-4}$ $7.6x10^{-4}$ $3x10^{-4}$ $1.9x10^{-3}$	90.5 0.56 8.7	61.1 0.01 0.1 $4.2x10^{-4}$ $1x10^{-4}$ $4.5x10^{-4}$ $1x10^{-3}$ $5x10^{-5}$ $3x10^{-4}$	0.001-0.1 0.01-1	62 0.2 23	19.7 (⩽0.01) (0.01
O	He^{2} * Ne^{10} * Ar^{18} * Kr^{36} * Xe^{54} * Rn^{86}	- - - - -	$10^{-6}-10^{-5}$ $10^{-8}-10^{-7}$ $5x10^{-6}-5x10^{-5}$ $5x10^{-8}$ $5x10^{-8}$ $2x10^{-17}$	- - - - -	$10^{-6}-10^{-5}$ $1.4x10^{-7}$ $6x10^{-7}$	- - - -			

TABLE 7. Distribution of chemical elements in the substance of meteorites, percent by weight (concluded)

	Elements	Silicate fraction of stony meteorites		Metal fraction of iron meteorites		Troilite		Schreibersite	Chromite
		After Brown [23]	This paper	After Brown [23]	This paper	After Brown [23]	This paper		
Lanthanides	Ce^{58}	2.5×10^{-4}		-		-			
	Pr^{59}	1×10^{-4}		-		-			
	Nd^{60}	3.7×10^{-4}		-		-			
	Pm^{61}	-		-		-			
	Sm^{62}	1.3×10^{-4}		-		-			
	Eu^{63}	3.3×10^{-5}		-		-			
	Gd^{64}	2×10^{-4}		-		-			
	Yb^{65}	6.4×10^{-5}		-		-			
	Dy^{66}	2.5×10^{-4}		-		-			
	Ho^{67}	7.2×10^{-5}		-		-			
	Er^{68}	2.1×10^{-4}		-		-			
	Tu^{69}	3.8×10^{-5}		-		-			
	Yb^{70}	2×10^{-4}		-		-			
	Lu^{71}	6.5×10^{-5}		-		-			
Actinides	Th^{90}	2×10^{-4}	3×10^{-5} ?	4×10^{-6}	3×10^{-6}	-			
	Pa^{91}		3×10^{-12}						
	U^{92}	4×10^{-5}	1×10^{-5}	7×10^{-7}	3×10^{-7}	-	1×10^{-8}		

* Content in cm^3/g

(0.8 percent); and, by the unavoidable admixture of metal in the non-magnetic fraction. Nothing is said concerning the effect of imperfections in the methods for determining small amounts of several elements.

For these reasons many students, including both J. and W. Noddack, as well as Goldschmidt, Sandell, Rankama, Brown, and others, subsequently have introduced substantial corrections for individual results of that work.

As new material was accumulated, different authors compiled more precise data on the chemical composition of individual meteorite fractions. Notable among such works were those of Goldschmidt [22], 1938, and Brown [23], 1949.

Recent years have seen the appearance of more papers on the determination of trace elements in meteorites. As a consequence, there came to be a need for another review of all data.

This paper is a refinement of Brown's summary, based on the latest publications.[2] For comparison, Brown's data are given in Table 7 along with the refined figures; the elements are arranged according to the Mendeleyev system with the lanthanides and actinides isolated.

The table gives the composition for the silicate fraction of stony meteorites and the metal fraction of iron meteorites; and, of the minerals troilite, schreibersite, and chromite in the iron meteorites.[3]

All results are as percentages by weight, except for the inert gases, whose contents are given in cm^3/g.

It appears from the table that our figures differ substantially, in a number of instances, from those of Brown. One reason for this is that Brown derived the content of elements in the silicate and metal fractions from comparatively restricted material: i.e. 107 stony meteorites with a haphazard ratio of different subclasses (chondrites and calcium-rich and calcium-poor achondrites) and 220 iron meteorites [5, 17]. In addition, Brown's work preserved many of the 1930 data in the paper by J. and W. Noddack [4], as described above.

In Table 7, content in the silicate fraction of stony meteorites of such elements as Mg, Ca, Al, Ti, Si, P, Cr, O, Mn, H, Fe, Co and Ni has been computed from the data in Urey and Craig [18], who used the most precise of the analyses for 140 stony meteorites. Consideration was given to the ratio of the number of chondrites, calcium-poor achondrites, and calcium-rich achondrites; approximately 89:3:4.

The contents of Cu, C, P, S, Fe, Co, and Ni in the metal fraction of iron meteorites have been derived from the present authors' figures on analyses of 373 meteorites in this class.

The remaining data are from recent works; in these, improved analytical methods are combined with a painstaking selection of samples.

In view of the fluctuations in the results of individual analyses, figures in the table have been rounded off. This is principally a refinement of figures after J. and W. Noddack [4], used by Brown. A more or less close agreement is observed between the other results, which may serve to confirm them.

The following papers were used as sources for distribution of elements in the silicate fraction of stony meteorites:

Li, Sc, Zr - 1953a;
Na - 1955a, 1955b;
K - 1952a, 1955a, 1955b
Rb - 1952a, 1955a, 1956d, 1957i;
Cs - 1957c, 1957h;
Sr - 1953h, 1956g;
Ba - 1953a, 1957f;
Ra, Ac, Po, Rn, Pa - 1956a;
Ga - 1954a, 1956b;
Ge - 1956e;
Sn - 1957d;
Pb - 1955c;
As - 1955d;
Sb - 1955e (recount);
Mo - 1954b;
Cl - 1940a, 1953b;
Br - 1953b;
He - 1953f, 1955f, 1955g, 1957g;
Ne - 1936a, 1955f, 1957g;
Ar - 1955h, 1957g;
Kr, Xe - 1956f;
Th - 1941a, 1950a;
U - 1941a, 1950a, 1950b, 1953c, 1956c.

The concentrations of elements in the metal fraction of the iron meteorites were taken from the following papers:

Cu - 1957a;
Mg, Al - 1950c;
Ra - 1928a, 1947b;
Ga - 1957a;

[2] After this paper had gone to press, some additions to Brown's summary were made by B. Yu. Levin, S.V. Kozlovskaya, and A.G. Starkova [24]; by A.P. Vinogradov, for the silicate fraction of stony meteorites [25]; and, by Suess and Urey [26], for the composition of chondrites.

[3] The admixture content in similar minerals of stony meteorites may be different.

Ge - 1956e, 1957a;
Sn - 1957b, 1957d;
Pb - 1953c
N - 1947a;
As - 1955d;
Sb - 1955e;
Cr - 1957a;
Mo - 1954b;
Mn - 1950c; 1954a;
H - 1955i;
Cl - 1953b, 1953g
Br - 1953b;
He - 1953d, 1955g;
Ne, Ar - 1955j
Th - 1952b, 1953g, 1954c;
U - 1950b, 1952b, 1953e, 1954c.

The contents of certain elements in troilite were taken from the following authors:

Al, Si - 1950c;
Cu, Mg, Mn - 1950c, 1957e;
Ge, Cr, Ni - 1950c, 1954a, 1957e;
Sn - 1954a;
Pb - 1953c, 1954a, 1957c;
Ti, V, Co - 1957e;
As - 1955d;
U - 1941a.

The composition of the main components of schreibersite, Fe, Ni and P, is taken from 38 published analyses. Content of the other elements is from the following works:

Cu, Ge, Cr - 1950v, 1954a;
Mg, Al, Si, Mn - 1950v;
Sn, Co - 1954a.

Content of Mg, Cr, and Fe in chromite is taken from 17 published analyses. Admixtures of Al, Ti, Si, Ge, V, Mn, Co, and Ni are from analyses of the Sikhote-Alin meteorite (1950v). In our opinion, some of the figures in Brown (marked with "?") are too high, apparently, for the following reasons:

Cu in silicate [4], because of contamination of the sample with metal;
Ca in metal [4], because of contamination of the sample with silicate;
P in troilite [4], because of contamination of the sample with schreibersite;
and S in silicate, because the summary gives the S content in stony meteorites, including troilite.

Table 7 gives a general picture of the individual elements between the phases and certain minerals in meteorites. For better understanding of the subject, however, one must have data on change in composition of the phases and individual minerals (in regard to minor admixtures) from one subclass, divided into families by groups, to another.

Determinations of certain rare elements in meteorites of different types are being made at present by a number of investigators. After sufficient material has been accumulated, these results may by systematized in order to draw definite geochemical conclusions.

[Ed.: The following designations of composition in this paper do not appear in Dana's Manual of Mineralogy, 4th Edition:

amphoterite	howardite
angrite	lodranite
bustite	nakhlite
chassignite	obrite
chladnite	rhabdite
diogenite	rodite
eucrite	sherghottite
grahamite	ureilite]

References for Table 7

1928 a Paneth, F., Zeitschr. Electrochemie, v. 34, p. 645.
1936 a Strock, L. W., Neue Folge, v. 1, no. 15, p. 171.
1940 a Selivanov, L. C., Doklady, Akademiya Nauk SSSR, v. 28, p. 809.
1941 a Evans, R., and Gudman, C., Bull. Geol. Soc. Am., v. 52, p. 459.
1947 a Nash, L., and Baxter, G., J. Am. Chem. Soc., v. 69, p. 2534.
1947 b Henderson, E., and Perry, S., Smithsonian Misc. Coll., v. 107, no. 13, p. 4.
1950 a Chackett, K., Golden, J., Mercer, E., Paneth, F., and Reasbeck, P., Geochim. et Cosmochim. Acta, v. 1, no. 1, p. 3.
1950 b Davis, G., Am. J. Sci., v. 248, p. 107.
1950 c Yavnel, A. A., Meteoritika, v. 8, p. 134.
1952 a Ahrens, L., Pinson, W., and Kearns, M., Geochim. et Cosmochim. Acta, v. 2, no. 4, p. 229.
1952 b Paneth, F., Reasbeck, P. and Mayne, K., Geochim. et Cosmochim. Acta, v. 2, no. 5-6, p. 300.
1953 a Pinson, W., Ahrens, L., and Franck, M., Geochim. et Cosmochim. Acta, v. 4, no. 5, p. 251.
1953 b Behne, W., Geochim. et Cosmochim. Acta, v. 3, no. 4, p. 186.
1953 c Patterson, C., Brown, H., Tilton, G., and Inghram, M., Physical Review, v. 92, no. 5, 1. 1, 234.
1953 d Chackett, K., Reasbeck, P., and Wilson, E., Geochim. et Cosmochim. Acta, v. 3, no. 6, p. 261.
1953 e Dalton, J., Golden, J., Martin, G., Mercer, E., and Thomson, S., Geochim. et Cosmochim. Acta, v. 3, no. 6, p. 272.
1953 f Burkser, E., and Kotlovska, F., Geol. zhurnal, v. 13, no. 3, p. 78.
1953 g Maurwitz, B., Hegedus, M., Gzelenyi, T., Fold Kozl., v. 83, no. 4-6, p. 138.

1954 a Goldschmidt, V., Geochemistry, Oxford, (work of Goldschmidt and his collaborators; 1931-1933, 1935, and 1938).
1954 b Kuroda, P., and Sandell, E., Geochim. et Cosmochim. Acta, v. 6, no. 1, p.35.
1954 c Dalton, J., and Thomson, S., Geochim. et Cosmochim. Acta, v. 5, no. 2, p. 35.
1955 a Edwards, G., and Urey, H., Geochim. et Cosmochim. Acta, v. 7, no. 3-4, p. 154.
1955 b Edwards, G., Geochim. et Cosmochim. Acta, v. 8, no. 5-6, p. 285.
1955 c Patterson, C., Geochim. et Cosmochim. Acta, v. 7, no. 3-4, p. 151.
1955 d Onishi, H., and Sandell, E., Geochim. et Cosmochim. Acta, v. 7, no. 1-2, p. 1.
1955 e ____________, Geochim. et Cosmochim. Acta, v. 8, no. 4, p. 213.
1955 f Gerling, E., Byull. Komiss. po opredel. abs. vozr., no. 1, p. 57, Doklady, Akademiya Nauk SSSR, v. 107, no. 4, p. 559, 1956.
1955 g Reasbeck, P., and Mayne, K., Nature, v. 176, no. 4474, p. 186.
1955 h Gerling, E., and Rik, K., Doklady, Akademiya Nauk SSSR, v. 101, no. 3, p. 433.
1955 i Edwards, G., Nature, v. 176, no. 4472, p. 109.
1955 j Reasbeck, P., and Mayne, K., Nature, v. 176, no. 4485, p. 733.
1956 a Vinogradov, A. P., Geokhimiya, no. 1, p. 6.
1956 b Onishi, H., and Sandell, E., Geochim. et Cosmochim. Acta, v. 9, no. 1-2, p. 78.
1956 c Starik, I., and Shats, M., Geokhimiya, no. 2, p. 19.
1956 d Herzog, L., and Pinson, W., Am. J. Sci., v. 254, no. 9, p. 555.
1956 e Wardani, S., Geochim. et Cosmochim. Acta, v. 10, no. 5-6, p. 321.
1956 f Gerling, E., and Baranovskaya, N. V., Meteoritika, v. 14, p. 113.
1957 a Lovering, J. F., Nichiporuk, W., Chodos, A., and Brown, H., Geochim. et Cosmochim. Acta, v. 11, no. 4, p. 263.
1957 b Winchester, J. W., and Aten, A. H. W., Geochim. et. Cosmochim. Acta, v. 12, no. 1-2, p. 57.
1957 c Gordon, B. M., Friedman, L., and Edwards, G., Geochim. et. Cosmochim. Acta, v. 12, no. 1, p. 170.
1957 d Onishi, H., and Sandell, E., Geochim. et. Cosmochim. Acta, v. 12, no. 3, p. 262.
1957 e Lovering, J. F., Geochim. et Cosmochim. Acta, v. 12, no. 3, p. 238.
1957 f Hamaguchi, G. W., Reed, G. W., and Turkevich, A., Geochim. et Cosmochim. Acta, v. 12, no. 4, p. 337.
1957 g Reynolds, J. H., and Lipson, J. I., Geochim. et Cosmochim. Acta, v. 12, no. 4, p. 330.
1957 h Cabell, M. J., and Smales, A. A., The Analyst, v. 82, p. 390.

REFERENCES

1. Yavnel, A. A., Meteoritika, v. 25, p. 115, 1958.

2. Farrington, O. C., Field. Mus. Nat. Hist., Geol. Ser., v. 3, p. 57, 1907.

3. Chirvinsky, P. V., Meteoritika, v. 5, p. 39, 1949, [see Michel, H., Fortschr. Min. Krist. Petr. v. 7, p. 294, 1922.

4. Noddack, J., and Noddack, W., Naturwiss., v. 18, p. 757, 1930.

5. Brown, H. S., and Patterson, C., J. Geol., v. 55, p. 508, 1947.

6. Buddhue, J. D., Popul. Astron., v. 54, p. 541, 1946.

7. Chirvinsky, P. N., Meteoritika, v. 4, p. 71, 1948.

8. Daly, R. A., Bull. Geol. Soc. Am., v. 54, p. 401, 1943.

9. Prior, G. T., and Hey, M. H., Catalogue of meteorites. London, 1953.

10. Chirvinsky, P. N., Izv. Akad. Nauk SSSR, v. 11, p. 387, 1917.

11. Chirvinsky, P. N., Izv. Donsk. Politekhn., v. 6, otd. II, p. 1, 1918.

12. Chirvinsky, P. N., Meteoritika, v. 6, p. 54, 1949.

13. Merrill, G. P., Am. J. Sci. (4), v. 27, p. 469, 1909.

14. Farrington, O. C., Field Mus. Nat. Hist. Geol. Ser., v. 3, p. 195, 1911.

15. Merrill, G. P., Nat. Acad. Sci. Mem., v. 14, I, p. 29, 1916.

16. Merrill, G. P., U. S. Nat. Mus., Bull., v. 149, 1930.

17. Brown, H. S., and Patterson, C., J. Geol., v. 55, p. 405, 1947.

18. Urey, H. C., and Craig, H., Geochim. et Cosmochim. Acta, v. 4, no. 1-2, p. 36, 1953.

19. Wiik, H. B., Geochim. et Cosmochim. Acta, v. 9, no. 5-6, p. 279, 1956.

20. Chirvinsky, P. N., Meteoritika, v. 2, p. 93, 1941.

21. Washington, H. S., Am. J. Sci., v. 9, p. 351, 1925.

22. Goldschmidt, V. M., Geochemische Verteilungsgesetze der Elemente, v. 9, Oslo, 1938.

23. Brown, H. S., Rev. Mod. Phys., v. 21, no. 4, p. 625, 1949.

24. Levin, B. Yu., Kozlovskaya, S. V., and Starkova, A. G., Meteoritika, v. 14, 1956.

25. Vinogradov, A. P., Geokhimiya, no. 1, p. 6, 1956.

26. Suess, H., and Urey, H., Rev. Mod. Phys., v. 28, no. 1, p. 53, 1956.

GEOBOTANICAL MAP OF THE U.S.S.R.[1]

by

V. B. Sochava[2]

• *translated by Marcella Woerheide* •

ABSTRACT

A newly compiled geobotanical map of the U. S. S. R. scale 1:4, 000, 000 is described. Two hundred and ten categories of vegetation are mapped, classified under 15 major groups. The relation of the mapped vegetation units to climate, soil, ground condition (permafrost), watersheds, and major geomorphic features is emphasized. -- M. Russell.

* * *

Geobotanical sketch maps show the spatial distribution of the basic vegetation formations in relation to the conditions governing their existence. The reflect the special characteristics of the structure of the vegetative cover in relation to the geographical habitat and its changes from place to place. A geobotanical map sums up all that is known about the vegeation of a territory and brings together all the disconnected information about it. At the same time it serves as a factual basis, indicating many geographical laws governing vegetation which cannot be determined within the map. The practical value of sketch maps of natural features is particularly great at the present time, when we are faced with the problem of maximum utilization of the natural resources of all the regions of our country.

Maps indicating vegetation characteristics of one kind or another were drawn up in Russia as early as the 18th century, but geobotanical mapping, proper, was originated on the basis of V. V. Dokuchayev's study of the zones of nature. The first geobotanical maps of the entire area of Russia was drawn up by V. V. Dokuchayev's pupil, V. I. Tanfil'yev (1900). It differed substantially from the foreign geobotanical maps of that time in that the vegetation was indicated on it in indissoluble relation to the geographical habitat and to soils in particular.

Geobotanical mapping became especially developed in the U. S. S. R. after the beginning of the twenties. A great contribution was made by the corresponding member of the U. S. S. R. Academy of Sciences, N. I. Kuznetzov, who supervised the plotting of many geobotanical maps of various regions, mainly of the European part of the U. S. S. R. He drew up some of these maps himself.

In 1939 a vegetation map of the entire U. S. S. R. on a scale of 1:5, 000, 000, edited by E. M. Lavrenko, was published. Until recently it was the largest-scale geobotanical sketch map of the country. The considerable scope of geobotanical research in the U. S. S. R. in recent years contributed to the substantial increase of data on the vegetation of our country. This permitted the Department of Phytogeography and Cartography of the V. L. Komarov Botanical Institute of the U. S. S. R. Academy of Sciences to draw up, under the supervision of E. N. Lavrenko and V. B. Sochava, a new geobotanical map of the U. S. S. R. on a considerably larger scale (1:4, 000, 000). The authors of the map are: B. N. Gorodkov, T. I. Isachenko, E. M. Lavrenko, A. N. Lukicheva, L. F. Rodin, N. L. Rubtzov, A. M. Semenova-Tyan-Shanskaya, and V. B. Sochava. Other members of the V. L. Komarov Botanical Institute and members of the science academies of the Republics and of the affiliates of the U. S. S. R. Academy of Sciences also participated in this work. A. A. Gebikh was the technical editor of the map.

The new map is the largest-scale representation of the vegetation of the entire U. S. S. R. It differs from the above-mentioned 1939 map by considerably greater detail, owing both to the larger scale and the consequently fuller utilization of the scale possibilities.

Two hundred and ten categories of vegetation are indicated, chiefly of vegetation formations and groups of vegetation associations. A hundred and nine color-hachure symbols, and also letter-number indexes, are used to indicate them. Many special features of the vegetation (distribution of different tree species and scrub groups, abundance of ephemeral and ephemeroid [sic] vegetation and others) are indicated on the map with larger-than-scale symbols. The legend of the map contains approximately 70 larger-than-scale symbols.

All the vegetation subdivisions which appear on the map are classified in the following groups:

---

[1]Translated from Geobotanicheskaya karta SSSR, Priroda, Izdatelstvo Akademiya Nauk SSSR, 1954, no. 10, p. 36-42. Published with permission of Director, U.S. Geological Survey.

[2] U.S. Geological Survey.

1. Arctic deserts and tundras.
2. Dark-coniferous forests.
3. Pine forests.
4. Larch forests.
5. Birch and aspen.
6. Coniferous-broadleaf forest.
7. Broadleaf forests.
8. Mountain fruit-tree forests and mountain scrub.
9. Meadows and grassy swamps.
10. Sphagnum swamps.
11. Xerophytic sparse forests, highland xerophytes and subtropical steppes.
12. Steppes and agricultural lands on their sites.
13. Semi-scrub wormwood [Artemisia] and saltwort [Salsola] deserts.
14. Haloxylon and scrub deserts.
15. High-mountain cushion-like vegetation.

Indicated separately are the lichen-algae vegetation of the takyrs, the perennial snow areas with the consociations of algae indigenous to them in different places, and the sparse vegetation of the rocky high mountains.

On small-scale geobotanical maps it is important to indicate both the presently existing vegetation and the vegetation which are characteristic of the corresponding territory before it underwent cultivation. In the forest zone, amidst the cultivated lands, there are often large areas of birch, and sometimes pine, forests which sprang up after fellings and forest fires on the sites of former dark-coniferous or broadleaf forests. Both from the theoretical and the practical point of view, it was very important to indicate on the map the distribution, not only of the presently existing vegetation formations and cultivated lands, but also of the vegetation which existed on them in the past. This so-called "reconstructed" vegetation very often indicates rather subtly the ecological possibilities of the territory, which are important to know, for example, when new plants are being introduced into cultivation and in a number of other cases.

On the 1939 "Vegetation Map of the U. S. S. R." only the "reconstructed" vegetation was indicated. The new map reflects, for the first time for the entire U. S. S. R., the distribution of the presently existing vegetation. In addition to this, the wild vegetation which are indigenous in the past to the cultivated lands, is indicated (for example, agricultural lands on the site of coniferous-broadleaf forests or on the site of meadow steppes, etc.). This cartographic method has considerable advantages for various practical purposes.

Vegetation, as is known, offers a rather variegated picture which is impossible to represent in all its details, not only on a small-scale but also on a medium-scale map. In connection with this, there arises the question of the principles of generalization of data for indicating them on a sketch map. In drawing up the geobotanical map in question, the authors were guided by the necessity of reflecting the typical features of the vegetation of the corresponding territories which are the most characteristic for the given geographic habitat. At the same time, the possibility of coordinating the special characteristics of the geographic distribution of vegetation formations with the newest relief, soil, and other such maps, was of great importance. Thus the new geobotanical map not only shows the distribution of vegetation over the territory of the U. S. S. R, but also fixes its relation to the habitats. This relation--in other words, the unity of organism and habitat--is also the basis of the classification of vegetation, worked out by the authors of the map and represented by its legend.

Even for a limited area, not only a single vegetation formation but a natural combination of vegetation formations is very often typical in the above-mentioned sense.

Such complexes were most often ignored up to now on sketch maps, and usually only one dominant formation was shown. In the legend of the new geobotanical map the main combinations of vegetation formations are shown in most cases.

The map fragment, showing the vegetation of the regions adjacent to the Baikal (see "Fragment" fig. 1), covers approximately 0.025 of the entire area of the U. S. S. R. It shows the vertical zonation of the vegetation and the diversity in character of this zonation in the Eastern Sayan, northern Baika., and southern Transbaikal Mountains. The fact that the steppe vegetation is confined to the hollows, with their drier climate and soils of the chernozem type, is graphically represented.

The fine turf steppes (80), where they are not tilled, have been since time immemorial the pastures used by the local animal husbandry. On their sites by means of suitable agricultural engineering methods, the foremost collective farms in recent years have established highly-productive forage lands. The meadow steppes (75 tz. s. and 75 zb.) constitute a rich, partly still-potential hay reserve which, combined with the forests, represents the peculiar landscape of the central Siberian and Transbaikal forest-steppes. The dark-coniferous forests (18) are concentrated on the moister slopes. In the upper reaches of the Lena River, they are characteristic of the highest location and in relation to the widely distributed scrub and grass-scrub larch forests (30 s.), they occupy a higher level of the relief. The dwarf pine-larch forests (38) cover large areas in southern Transbaikal, and they are also distributed in the Eastern Sayan Mountains, which proves the similarity between these landscapes.

The mountain larch forests (36), which cover large areas in the northeast, are good hunting grounds and partly lumbered forests. These forests are very important from the water and soil conservation point of view. The vast mountain tundras (3) are likewise important, although their full economic utilization still lies in the future. West of Baikal there are frequent large masses of agricultural lands on the site of tiaga forests (105). In the northwestern corner there are large areas covered with birch stands (41) which sprang up recently, chiefly on the site of dark-coniferous forest.

The principal law of distribution of the basic vegetation formations over the vast territory of our country is zonation. Already on the first geobotanical maps of Russia, drawn up at the time of V. V. Dokuchayev, this law was clearly evident. The new geobotanical map makes it considerably more precise and sheds new light on the concept of the zonation of vegetation and its special characteristics in the various regions of the U. S. S. R. Whereas formerly the zonal characteristics of the vegetation were represented on the maps more in the form of a generalized plan, now they are represented in a more concrete form, reflecting the local characteristics of the vegetation against the background of the general zonal law. Such a representation of the vegetation is very necessary for the further treatment of the geobotanical and complex natural regionalization of the U. S. S. R.

The zonation of the vegetation manifests itself differently in the various natural regions of the country. It is most diverse in the eastern part of the Russia plain where, from the north to the south, the following vegetation subzones alternate: arctic tundra, moss-lichen tundra, forest-tundra, northern taiga, middle taiga, southern taiga, coniferous-broadleaf forests, meadow steppe with islands of broadleaf forests (forest-steppe), typical turf-grass steppe (desert turning into steppe and typical desert). The desert zone formations are confined to the northern edge of the Aral-Caspian depression, where the desert vegetation advances further north than in other places. In the western part of the Russian plain, the zonation of the vegetation is already different. There the arctic and moss-lichen tundra zones are absent, the coniferous-broadleaf and broadleaf forest zones are considerably more widely represented, and the zonal types of desert and southern semi-desert vegetation are absent. This is due, primarily, to the greater mildness of the climate under the influence of the air coming from the Atlantic.

In western Siberia the arctic tundra subzone is more widely distributed than in the eastern part of the Siberian plain. Coniferous-broadleaf forests are replaced by birch-aspen forests, and broadleaf forests are completely absent. The steppe vegetation is also fundamentally different in its composition from the east European vegetation. The cold soils of the western Siberian lowlands, which are swamped in the north and brackish in the south, and the lower winter temperatures cause the great bleakness of the nature [sic - landscape?]. The northern taiga in western Siberia recalls the European forest-tundra. Swamps are fairly widely distributed in the forest-steppe and even in the steppe.

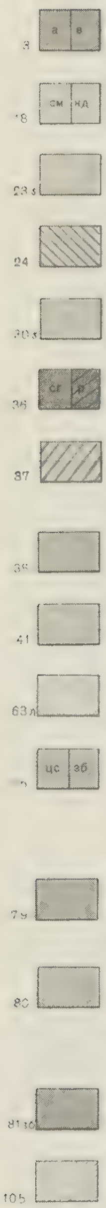
On the flat mountains of central Siberia the vegetation is even more peculiar. Larch taiga replaces the dark-coniferous forests there and steppe vegetation in the south is represented only by islands of meadow steppes. The subdivision of the forest zone into subzones is less distinct, which is promoted by the permafrost in the ground. The winter climate is relatively uniform, as is the dissection of the relief, causing vertical zonation nearly everywhere.

In the Far East only the tundra and forest zones are represented, their diversity of vegetation being caused to a great extent by the vertical, and not by the latitudinal, zonation.

The first experiments in dividing the vegetation of our country into zones and subzones (G. I. Tanfil'yev, 1900; L. S. Berg, 1913) were carried out by means of the analytical method: the vegetation of Russia was divided into generalized physionomic types, having a zonal distribution. At the present time, we are able to isolate the zonal types of vegetation by means of synthesis and at the same time by the analysis of the characteristics of the vegetation of separate geobotanical regions. A fuller and less one-sided representation of the zonal types of vegetation is thus obtained, with all the local characteristics inherent in them in the various regions.

For the purpose of revealing most clearly the general law of distribution of the zonal types of vegetation, in the lower left-hand corner of the new geobotanical map there is a special insert, on a scale of 1:20, 000, 000, (fig. 2, slightly reduced) which is also reproduced on the Fragment.: On this insert the distribution of 27 zonal groups of vegetation formations is represented in a generalized form. It clearly reveals the zonal law in the distribution of the tundra and forest vegetation formations. The division of the taiga into three zonal types -- northern, middle and southern taiga -- is preserved throughout the U. S. S. R. In the various regions these types of taiga are represented by their formations, which are different in the composition of the vegetation and in its ecological relationships. In the northwest, the zonal types of the taiga of the European part of the U. S. S. R. continue in Finland and Scandinavia, and, at the same time, all the boundaries of the zonal types of taiga vegetation are

LEGEND FOR FIGURE 1.



3. Mountain tundras, locally in conjunction with scrub and meadows:
3 a - Altai-Sayan; 3 b - east Siberian

18. Siberian mountain taiga dark-coniferous forests:
18 SM - chiefly mixed spruce-dwarf pine-fir, spruce-fir, and spruce-dwarf pine;
18 KD - with predominance of Siberian dwarf pine.

23s. Siberian grass scrub and scrub larch-pine forests with Larix sibirica, in conjunction with lichen-scrub pine forests.

24. Transbaikal-Amur grass-scrub larch-pine forests, turning into steppes and in conjunction with steppes in the south.

30s. Central Siberian middle taiga scrub and grass-scrub larch forests of the large and dense coniferous type, of Larix sibirica, often with pine.

36. Mountain east-Siberian middle taiga larch forests:
36 sg. - middle-mountain;
36 r - sparse forest at the upper mountain tree limit.

37. Mountain south-Siberian larch forests.

38. Mountain south-Siberian dwarf pine-larch forest, in conjunction with dwarf pine forests.

41. Birch and aspen forests, locally in conjunction with coniferous forests, meadows, and swamps.

63-1. Flood-plain meadows of the forest zone, usually in conjunction with scrub and forests (urëma) and agricultural lands on their site.

75. Meadow steppes and meadows turning into steppes, in conjunction with forest zones (forest-steppe):
75 tzs - agricultural lands on the site of central-Siberian meadow steppes and meadows turning into steppes, in conjunction with birch and pine-larch forests;
75 zh - Transbaikal meadow steppes, meadows turning into steppes, and agricultural lands on their site, in conjunction with larch and pine forests.

79. Tansy (of Tanacetum sibiricum) Transbaikal steppes, in conjunction with peppergrass (Aneurolepidium pseudoagropyrum) and turf-grass steppes, and agricultural lands on their site.

80. Fine turf (of Koeleria gracilis, Festuca sulcata s. l., Poa botryoides, Cleistogenes squarrosa), less frequently of feather grass (Stipa capillata s.l.), Altai-Transbaikal steppes and agricultural lands on their site.

81zb. Bistort - "tyrsa" [?] and peppergrass - "tyrsa" [?] Transbaikal steppes and agricultural lands on their site.

105. Agricultural lands on the site of taiga forests.

SUPPLEMENTARY SYMBOLS

Dwarf pine (Pinus sibirica)

Pine (Pinus silvestris)

Siberian larch (Larix sibirica)

Dahur larch (Larix dahurica)

[This map is printed in color in Priroda, v. 10, opp. p. 38, 1954.]

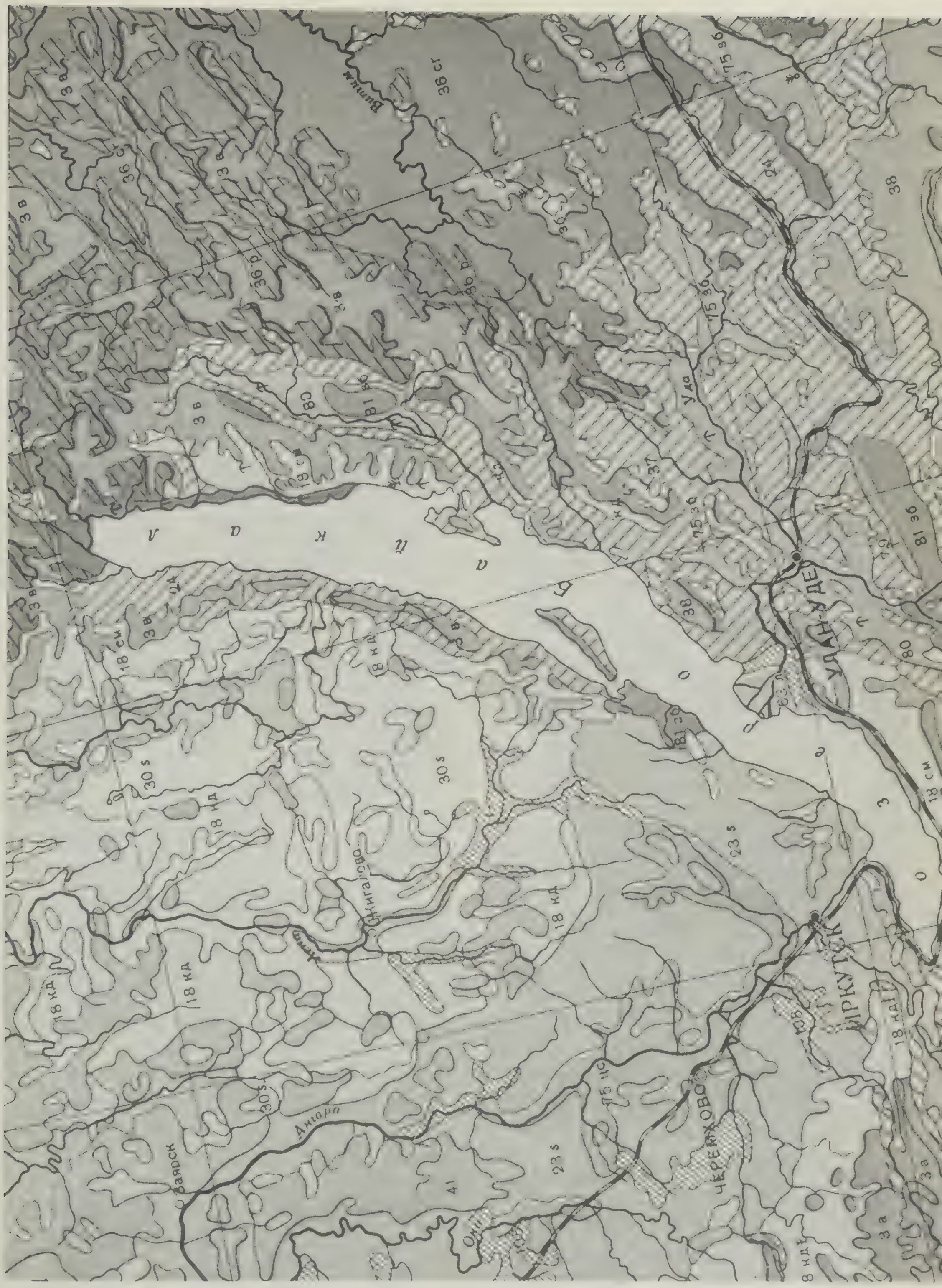


FIGURE 1. Fragment of the geobotanical map of the U.S.S.R.
Scale: 1:4,000,000
Prepared in the Botanical Institute, named after V. L. Komarov, of the Academy of Sciences of the U.S.S.R. under the direction of E.M. Lavrenko and V. B. Sochava

noticeably intermingled. In foreign literature, the zonal types of tiaga of Finland, Sweden and Norway have not been indicated on maps up to now, and they are represented for the first time on our chart. The coniferous-broadleaf forests, as is shown at first glance on the schematic map, are concentrated mainly in the U. S. S. R. Beyond the limits of our country, comparatively small areas in Poland, Finland, Sweden and Norway are related to the coniferous-broadleaf zone. In the east, in the Pacific Ocean basin, the coniferous-broadleaf forests are concentrated in the mountains.

The broadleaf forest zone is found only in the west and in the extreme southeast of our country. It is directly related to the similar zonal type in northwestern Europe, and also in Korea and Eastern China. In the U. S. S. R., it is represented by special groups of vegetation associations, the distribution of which, against the background of the agricultural lands, is shown on the map itself.

Subalpine birch sparse forest formations and meadow vegetation of the subarctic type are still more disconnected and are found only in the extreme northeast and extreme northwest of Eurasia. This vegetation of the cold maritime climate regions in the U. S. S. R. is most fully represented on the Kamchatka Peninsula and on the Komandorskie and Kuril Islands. The meadow steppe zone, which corresponds to the forest steppe, in the form of a continuous belt, extends only within the limits of the Russian plain and in the western Siberian lowlands. East of the Yenisei River, meadow steppes occur in relatively small separate masses. South of the steppe zone proper (areas where turf-grass steppe consociations predominated in the past, and where they are still widely distributed in certain places), from the Caspian Sea region in the west to the Zhekhe [sic - transliterated from the Russian, which was a Russian transliteration of a Chinese name] province in China, extends, for a thousand kilometers, a semi-desert zone in which large masses of valuable agricultural lands are concentrated. The semi-deserts on the map are divided into two zonal types: northern and southern semi-deserts, the natural characteristics of which should be taken into account when the lands are placed under cultivation and when various measures are taken for the improvement of the pastures.

The desert vegetation is subdivided on the map into 16 basic groups of formations, which, in turn, are composed of many variants. They are all different from the point of view of their economic utilization possibilities and are combined into two zonal types: typical and ephemeral deserts.

Indicated for the first time on the geobotanical map of the U. S. S. R., and correspondingly on the chart of the distribution of zonal types of vegetation, are the subtropical foothill steppes (Kopet Dagh, Badghis, the Parmi-Alai and western Tien Shan foothills). These are mainly grass and partly sedge consociations and also consociations of various coarse grasses, which are always confined to rich soils -- the "sierozem" [gray desert soils]. Some authors call them savannoids, or semi-savannas. From the economic point of view, these lands, by means of suitable agricultural engineering methods, would be good for highly-productive grain farming, for orchards with various kinds of fruit trees, and for subtropical crops.

The new geobotanical map reflects the diversity of the vegetation of the mountain regions. At the same time, it shows clearly the local peculiarities of the vertical zonation, inherent in the separate mountain regions. This is the basis for distinguishing the different types and variants of the vertical zonation of the vegetation in the mountains of the U. S. S. R.

The mountain vegetation, which is distributed over a considerable area, is very diverse. Large masses of mountain steppes and meadows turning into steppes are concentrated in the mountains of Central Asia. West of them, masses of mountain steppes and consociations of highland xerophytes occur in Fore-Asia and on the flat mountains of the Southern Caucasus. In the east there is a region of mountain steppes on the Altai Mountains and in Tuva which is closely related to the steppe areas of Mongolia and other regions of Central Asia adjacent to it. All these mountain steppe regions are somewhat isolated and have their own characteristic vegetation. At the same time, they border upon one another and form a single mountain steppe belt.

The mountain tundras are primarily concentrated in the mountain taiga regions, where they cover the tops of many mountain ranges. The most considerable masses of them extend over the northwestern part of the Middle-Siberian flat mountains and in the Verkhoyansk-Kolyma mountain region.

Mountain tundras also extend into the arctic region and enter into contact with the plain-tundra consociations. On the other hand, the southern Siberian mountains (Altai, Sayan) and the adjacent mountain ranges of Mongolia constitute a geobotanical unit, within the limits of which large masses of mountain tundras, mountain steppes and alpine meadows are distributed in close proximity to one another. There, at the present time, a floral interchange is possible between the above-mentioned formations. In the mountains of Central Asia, the mountain steppes edge the subalpine meadows, in the composition of which steppe plants are often found.

The mountain coniferous-broadleaf and broadleaf forests also have a zonal distribution, but they are represented by disconnected masses: European, Caucasus-Asia Minor, Middle-Central Asian, and Far Eastern. The largest of them are the peripherous ones, which are under the influence of the Atlantic and Pacific Oceans. These masses differ sharply in the composition of their vegetation. The most similar to each other are the European and Caucasus-Asia Minor coniferous-broadleaf and broadleaf forest.

In the Far East, the mountain coniferous-broadleaf and broadleaf forests are directly adjacent to the moist subtropical forest formations, which is important from the point of view of the possible penetration of subtropical forest plants northward and of the northern plants into the subtropical zone. In the Far East there is also direct contact between the mountain coniferous-broadleaf and mountain taiga forest.

On the new map, the distribution of the largest masses of swamps is shown for the entire U. S. S. R., whereas on previous geobotanical sketch maps they are generalized with the zonal type of forest vegetation.

In the deserts of Middle Asia the cultivated vegetation of the oases is plotted. This gives an idea of the degree of utilization of the desert zone lands, of which it was not possible to judge from the vegetation sketch maps of the past.

The new geobotanical map of the U. S. S. R. enables one to begin computing the areas which are occupied by the main groups of vegetation formations, which is of indubitable interest for various kinds of planning estimates.

In addition, it is possible to note certain vegetation laws which appear for the first time on the new geobotanical map. In the northeastern mountains, in the Kolyma and Indigirka basin, above the mountain sparse larch forest belt, extends the dwarf pine [Pinus pumila] zone, the consociation of which occupies a large area. The climate of this zone is little known, but apparently the dwarf pine thickets there are concomitants of its moderate continental character, of the great humidity of the growing period, and of the snow cover in winter; that is to say, the natural conditions are very different from the sharply continental regime of the lower mountain and valley zone of northeastern Siberia.

Indicated on the northwestern shores of the Okhotsk Sea, which were usually related entirely to the forest zone, are separate areas of tundra vegetation, which is found on the flat surfaces amidst mountain-sparse forest at 59° north latitude. This is the southernmost island of tundra landscape in the U. S. S. R., the existence of which is favored by the influence of the Okhotsk Sea, cold in summer and covered with ice in the winter.

The investigations of recent years have defined more accurately the boundaries of dark-coniferous forest distribution. The generalized area of distribution of all the species of dark-coniferous trees growing in the U. S. S. R. covers nearly the entire forest zone, considerable territories in the Caucasus and in the mountains of Middle Asia. However, throughout this entire vast area the dark-coniferous trees form considerable masses only in the regions where the climate is less continental and which are sufficiently humid and moderately cold. On the Russian plain, dark-coniferous forests, with a predominance of spruce, are distributed not only in the river valleys but also on the flat watersheds. This is favored by the climatic conditions and the relative drainage of the areas between the rivers. In the Western Siberia lowlands, dark-coniferous forests accompany the river arteries in a band of varying width, but on the watersheds they are found only in small strips along the hummocks and crests. This is caused by the poor drainage and swampiness of the watersheds and also by the more severe and continental climate.

On the Middle-Siberian flat mountains, the dark-coniferous forests select special locations: in the river valleys or on slight elevations, where the thermal regime is more favorable and the climate is less continental. Finally, the dark-coniferous plain taiga in the U. S. S. R. is most typical and widely distributed in the Russian plain, whereas in Siberia the mountain taiga dark-coniferous forest formations are the most characteristic.

One of the most considerable masses of mountain dark-coniferous forests is found on Sikhota-Alina. Investigations of recent years found masses of larch stands there among the spruce and pine-spruce consociations in the closed mountain hollows, which are more continental and less humid. The fact that the larch forests are confined to dry and cold hollows is clearly evident in other regions also.

East of the Yenisei River the larch forests predominate and considerable areas are covered by middle-taiga larches with a scrub and grass-scrub cover. They often occur on fertile soils and under relief conditions which are favorable for [agricultural] utilization.

In the forest zone, birch and partly birch-aspen forests usually spring up on the site of burned or felled coniferous stands. These forests are shown for the first time, for the entire U. S. S. R., on the geobotanical sketch map. In addition, it became clear that the greatest aspen-birch forest areas lie in western Siberia, on the Russian plain, and in the southern part of the Far East. They tend to replace the chiefly dark-coniferous forests

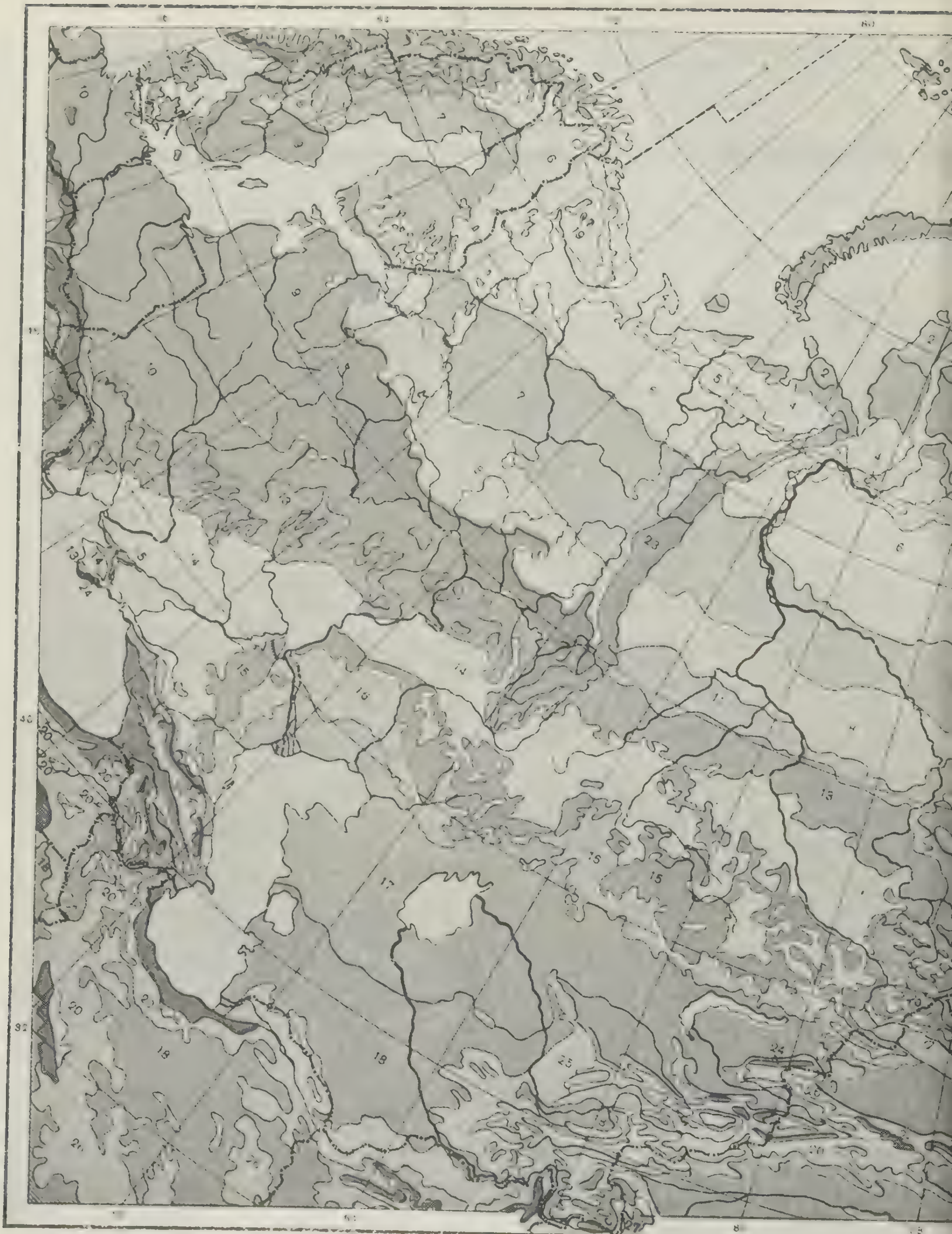
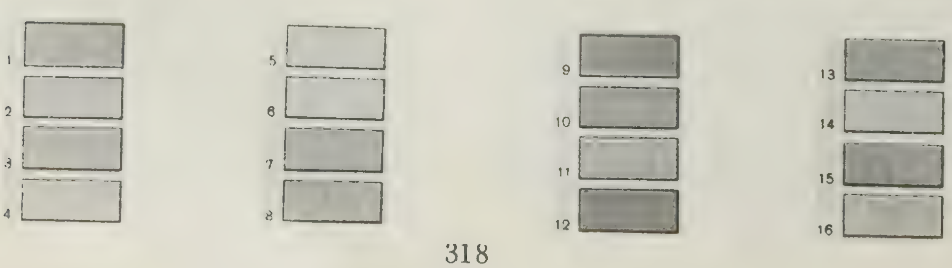
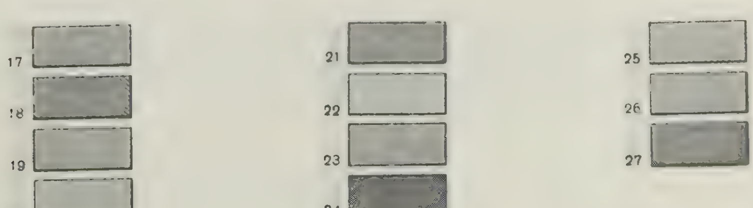


FIGURE 2. Chart of the distribution



of zonal types of vegetation



[Explanation next page]

LEGEND FOR FIGURE 2.

[Refer to legend boxes under map]

1. Arctic deserts and glaciers
2. Arctic tundras
3. Typical (moss and lichen) tundras
4. Scrub and tussock tundras
5. Fore-tundra sparse forests (forest-tundra)
6. Northern taiga forest
7. Middle tiaga forests
8. Southern taiga forest
9. Broadleaf-coniferous forests
10. Broadleaf forests
11. Needle-leaved forest
12. Evergreen subtropical forest
13. Meadow steppes (forest-steppe)
14. Typical (turf-grass) steppes
15. Desert (semi-scrub-turf-grass) steppes (northern semidesert)
16. Deserts turning into steppes (southern semidesert)
17. Typical (semi-scrub and scrub) deserts
18. Ephemeral (ephermeral-semi-scrub and ephemeral-scrub) deserts
19. Mountain tundras, scrub and sparse vegetation of high mountain taiga areas
20. High mountain alpine and subalpine meadows (sometimes turning into steppes) and sparse high mountain vegetation of the southern forest, steppe, and desert areas
21. Subalpine birch sparse forests and meadow vegetation of the subarctic islands.
22. Mountain northern taiga sparse forests
23. Mountain middle and southern taiga forests
24. Mountain broadleaf, broadleaf-coniferous coniferous forest of the southern forest, steppe, and desert areas
25. Subtropical fore-mountain steppes
26. Mountain steppes (chiefly Central and Middle Asia) and highland xerophytes in conjunction with mountain steppes (chiefly Fore-Asia)
27. High mountain deserts

Printed in color, Priroda, v. 10, opp. p. 40, 1954

/Note: The bar scale in the lower right hand corner of the map, as photographed without change from Priroda, appears to be in error by a factor of about two. The length shown as 500 km is more nearly 1000 km/

in the more southern regions, where the falls and burns are quickly transformed into meadows, preventing the regeneration of coniferous tress. In the northern taiga, the development of grassy vegetation after fires and fellings occurs considerably less vigorously, which is the reason that coniferous trees colonize the open spaces there very easily. In the continental regions of eastern Siberia, especially in the permafrost area and where larch stands predominate, there is very little birch and aspen.

On the 1939 vegetation map of the U.S.S.R., meadow steppes and meadows turning into steppes were shown in Central Yakutiya. This is one of the northernmost outposts of steppe vegetation in the U.S.S.R., which is caused by the dryness of the continental climate of the Central Yakutia basin. On the new map, the boundaries of the steppe type of consociations in Central Yakutiya are considerably altered and their area proved to be considerably smaller. In addition to this, the meadow steppes and meadows turning into steppes, in conjunction with forest consociations, appear over a very small area in another forest region - on the Khanka Lowlands. There, they constitute the northern outpose of the meadow steppes of northern China.

Considerable pasture areas lie in the semi-desert region of our country: in the northern [semi-desert area], where Artemisia-turf-grass steppes are combined with desert groups, and the southern [semi-desert area], typical of which are the grass-Artemisia consociations, which alternate with the turf-grass steppes and the Artemisia and saltwort deserts. Artemisia is the characteristic plant of the semi-desert. The recent efforts of a series of investigators have shown the considerable diversity of the Artemisia growing there, the species of which are widespread within the various regions and may be considered as the indicators of the local characteristics of the vegetation, and also, in the final analysis, of the ecological habitat. Eleven geographic types of semi-desert vegetation are shown on the map, which, in addition to the other characteristics, differ from one another in the Artemisia species which are indigenous to them. Such a breakdown of the semi-desert vegetation is important for the division of the forage lands into regions.

The great, and in certain places still potential, pasture and hay reserve is concentrated, in our country, in the mountains. The largest masses of alpine, subalpine, and middle mountain meadows, as well as of mountain steppes, which are indicated on the map, give an idea of this reserve. The great forage possibilities of the high mountains of Middle Asia and the Caucasus, as well as of Altai, are quite obvious.

The local peculiarities of the vegetation, which appear on the map, furnish the basis for a new and more exact geobotanical and natural division of the U.S.S.R. into regions, with the separation of the large basic subdivisions: the geobotanical provinces [sic] [regions] and subprovinces [sic] [subregions]. At the present time, this is particularly essential for the future planning of the allocation of the different branches of the economy and of the various types of agriculture, taking into consideration the natural characteristics of the locality.

The new geobotanical map of the U.S.S.R. will be useful and indispensable for coordinating and comparing the medium-scale vegetation maps of the republics, territories and districts. It should facilitate and expedite the plotting of such maps for the entire country, which is the immediate task of geobotanical cartography -- something that is very important from the practical point of view.

These medium-scale maps of the districts and republics, in turn, will facilitate the task of plotting large-scale geobotanical maps of the Kolkhoz and Sovkhoz territories, reflecting, in general and in detail, the quality of the natural pasture lands and the types of forest and scrub vegetation, as well as the vegetation of swamps, solonchaks, and other places which should be improved.

ON THE REACTION OF OLIGOCLASE WITH WATER UNDER CONDITIONS OF HIGH TEMPERATURE AND PRESSURE[1]

by

N. I. Khitarov[2]

• *translated by Michael Fleischer* •

ABSTRACT

Feldspar group minerals reacting with water at depth determine, by their reaction with environ ment, the character of newly formed minerals. Although plagioclase is the most abundant member of this group experimental data are very limited on the nature of its reactions under high pressure and temperature conditions. The author experimented on acid plagioclase with analytical data and physical constants corresponding to those of oligoclase. The reaction between oligoclase and water was studied under various pressures and temperatures, using a diffusion autoclave (previously described by the author [1]). Silicon, sodium, and aluminum in significant amounts went into solution; and, smaller amounts of calcium and potassium were observed. With increased temperature, larger amounts of material constituting oligoclase went into solution: The maximum occurred at 350 to 400° C; and, a marked decrease, at 500 to 600° C. Quantitative ratios of material in the condensate were found to correspond to albite indices. Increased pressure does not alter this behavior, there is only increased passage of separate components of the mineral into solution. At 350°, newly formed material was not observed microscopically; at higher temperatures, kaolinite and chalcedony appeared at sucessively higher temperatures. Experimentation by Morey and Chen on albite indicate that transfer of the albite component of oligoclase into solution is predominant. By comparison of its stability with that of two other minerals, albite is the most reactive with water. At 350° Centigrade and under pressure of 350 kilograms per square centimeter, the transfer into solution (in milligrams per liter) is for albite, 318; for microcline, 268; and, for oligoclase, 220. Labradorite was studied under analogous conditions; in that the transfer of labradorite predominates over that of the anorthite molecule, its behavior corresponds to albite. It was found that basic plagioclase shows less stability than is evident from microscopic examination of plagioclase in rocks. Data from these and previous experiments indicate possible types of solutions that can form within intragranular spaces in rocks by reaction between acid plagioclase and water. It is evident from the data that leaching of the albite component predominates by variation in composition of the solution throughout a wide range of temperature and pressure conditions. -- D. D. Fisher

***

Under deep-seated conditions where the influence of high temperature and pressure are expressed, minerals of the feldspar group undergo substantial alteration in the presence of water; this leads to the emergence of solutions of specific chemical composition.

As the result of subsequent reaction with environment, these solutions impose their impression on alterations taking place in rocks and minerals, and determine the character of the material thus newly-formed.

The most abundant representative of the feldspar group, i. e. plagioclase plays in this respect an essential role. The experimental data that characterize its behavior under conditions of high temperature and pressure in the presence of water, are very limited. With the purpose of expanding these, the following study was carried out; and, was begun with acid plagioclase.

We collected the mineral sample from one of the pegmatitic deposits of Karelia. From analytical data and optical characteristics, the material selected corresponds to oligoclase (nos. 23-24).

Composition of oligoclase (in percent)

SiO_2	62.83
Al_2O_3	24.28
CaO	4.30
MgO	0.12
K_2O	1.30
Na_2O	7.17 (by difference)
	100.00

Reaction of oligoclase with water under different temperature and pressure conditions

[1] Translated from O vzaimodeystvii oligoklaza c vodoy v usloviyakh povyshennikh temperatur i davleny: Akademiya Nauk SSSR, Institut Geologii Rudnykh Mestorozhdeny, Petrografii, Mineralogii i Geokhimii; Institut Khimii Silikatov, 1958, p. 208-213.

[2] Institute of Geochemistry and Analytical Chemistry U.S.S.R. Academy of Sciences

was studied with the assistance of chemists E. E. Filippov and T. N. Kozintsev and laboratory-mechanics S. V. Sidorova and P. V. Boitsova.

In the work there was used the diffusion autoclave, previously described (Khitarov, [1]). The autoclave chamber accommodating the horizontal resistance furnace, was charged with crushed oligoclase of 3 to 5 mm size. The water, intended to drop through the autoclave cavity, is supplied under pressure by a manometer controlled pump (fig. 1). The solution

amounts of silicon, sodium, and aluminum. Calcium and potassium were observed in small, subordinate amounts.

In Figures 2, 3, and 4 are represented isobars at 300, 600, and 900 kg/cm^2; these characterize solution content changes originating from reaction of oligoclase with water under varying temperature conditions.

With increased temperature of the medium in which the reaction of oligoclase and water proceeded, there was an increase in quantitative

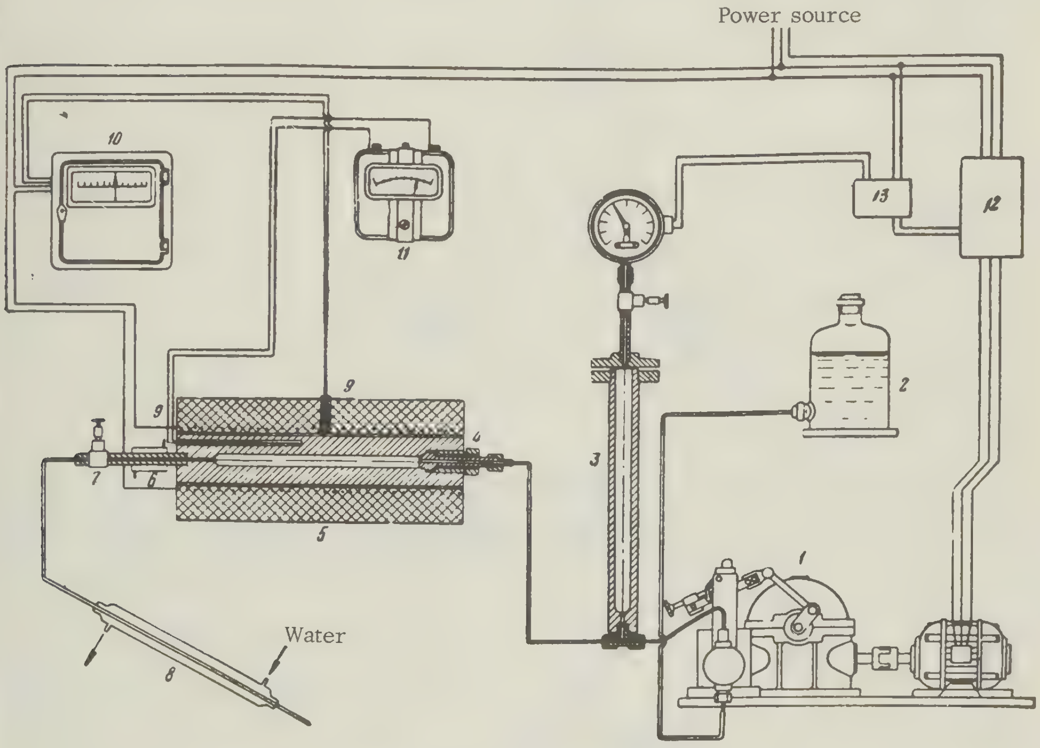


FIGURE 1. Diagram showing arrangement of diffusion reactor.

1) High pressure pump; 2) vessel with water; 3) shock absorber; 4) autoclave; 5) furnace resistance; 6) condenser; 7) valve for fine regulating; 8) condenser; 9) thermocouples; 10) electronic thermoregulator; 11) millivoltmeter; 12) magnetic starter; 13) relay.

produced after the reaction, falls from the autoclave cavity into the short refrigerator [condenser]; from there it proceeds through the high pressure valve into a glass condenser, and, is retained in the collecting flask as a condensate. The percolation speed of water is maintained in the range of 0.5 to 2 ml per minute. The duration of each experiment, under given conditions, was the same in all cases and equalled four hours. The condensate was analyzed.

Results of experimentation showed that, under the conditions of the experiment, significant

transfer into solution of material constituting the mineral. It attains a maximum in the temperature interval 350 to 400° C, and decreases markedly to 500 to 600° C. Apparently, the zone of the maximum coincides with the temperature zone adjoining the critical region for the originating solution.

With increasing pressure the previously mentioned regularities are not disturbed. Increased pressure preserves the maximum along the curves illustrating plagioclase stability in the presence of water, and causes only an increased passage into solution of separate

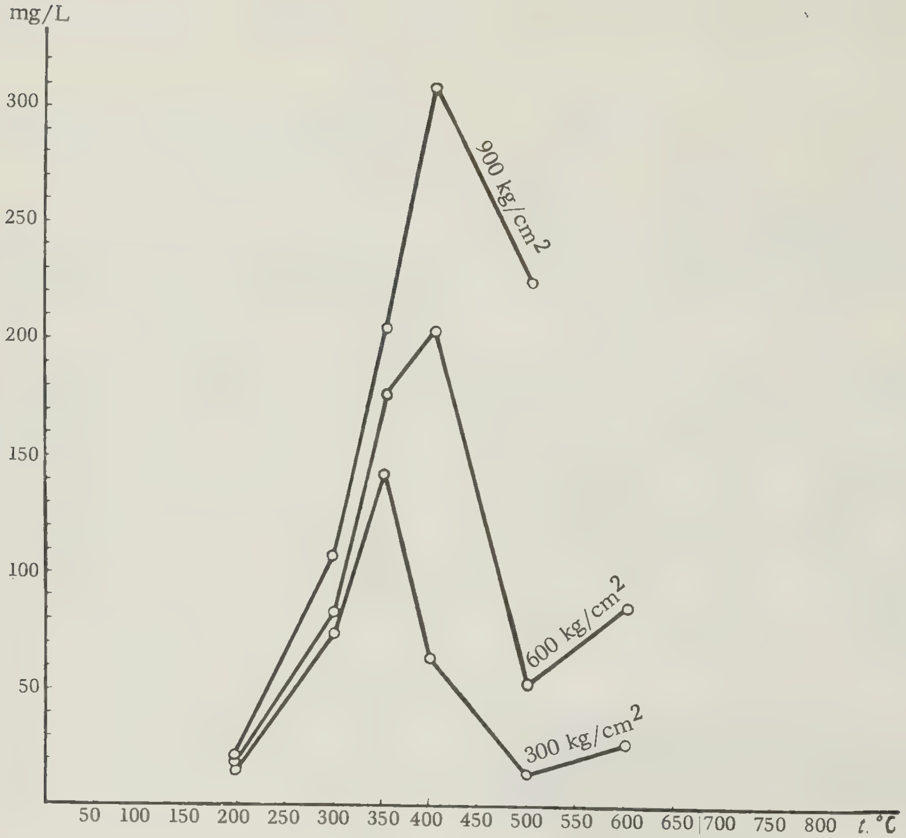


FIGURE 2. SiO_2 content (mg/L) in solution after reaction between oligoclase and water, in isobaric representation

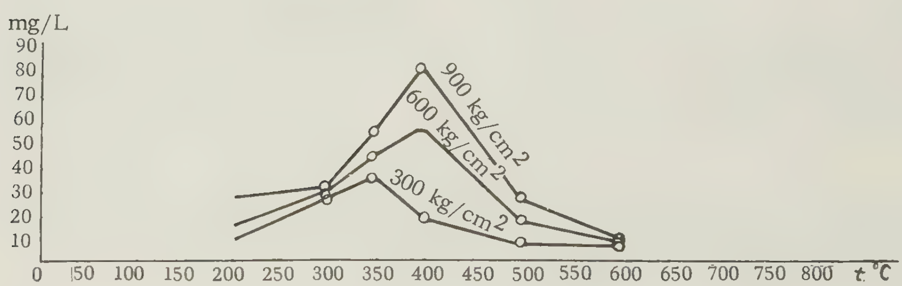


FIGURE 3. Al_2O_3 content (mg/L) in solution after reaction between oligoclase and water, in isobaric representation

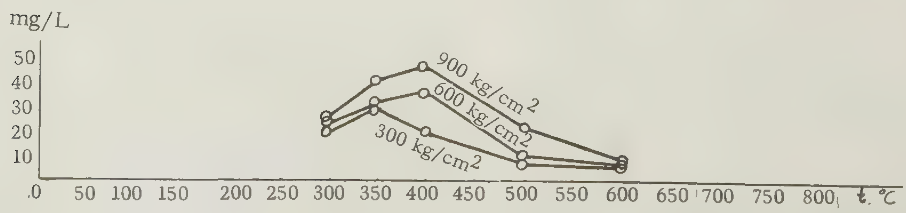


FIGURE 4. R_2O content (mg/L) in solution after reaction between oligoclase and water, in isobaric representation

components of the mineral.

Quantitative ratios of material found in the condensate after reaction with water, correspond to indices referable to albite. Albite ratios develop principally under prevalence of average-temperature conditions in the range studied (350 to 450° C). With temperature increase, the ratio changes toward predominance of silica, enriched in the solution. In the diagram (fig. 5) are given general characteristics

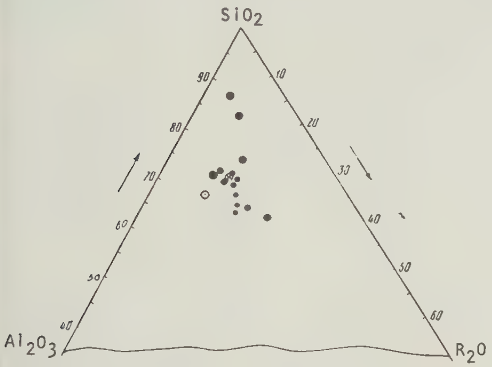


FIGURE 5. Diagram showing composition of solutions formed by reaction of oligoclase with water (deducting CaO). ⊗ albite, ⊙ oligoclase, theoretical deducting CaO.

for compositions of solutions formed as the result of reaction between oligoclase and water under various temperature and pressure conditions. Small amounts of CaO are deducted from the total content. The pH of the condensates varied within the limits 6.5 to 7.5.

After the experiments, microscopic characteristics of the mineral reveal little; because, amounts of time for exposure to given conditions were short and experiments were carried out under dynamic conditions.

Newly formed material was not observed microscopically in the material exposed in the autoclave at 350°. At higher temperatures, up to 400°, there appeared kaolinite which was also determined in the charges investigated for reaction with water at 500°. At higher temperatures, kaolinite was not found but chalcedony appeared. Presence of fine lamellar mica was noted after many experiments.

As was indicated above (see fig. 5), the predominant part of solution, forming as the result of the reaction of oligoclase with water, approaches the composition of albite in dissolved-material content. For some conditions this phenomenon may be analyzed in detail and compared with data in the literature. In a recent paper, Morey and Chen [2] give the results of treating albite at t=350° and P=350 kg/cm^2 with water in an experimental set-up similar to ours. The total amount of dissolved material in one L of condensate, after treatment of albite, was determined to be 318 mg; for oligoclase, we found 220 mg. Of this 220 mg, 3.3 percent is alloted to anorthite constituents as calculated from the CaO content in the condensate, leaving 96.7 percent for the albite constituents.

After treatment of oligoclase with water and after deduction of the anorthite portion of composition by calculation from the CaO content in solution, with the data of Morey and Chen for albite, comparison of the weights and molecular ratios of material found in solution may convince one that transfer into solution of the albite component of oligoclase (table 1) is predominant.

According to the data of Morey and Chen, the amount of albite going into solution, under the given conditions, equals 318 mg/L. Our experimental data for the albite composition after reaction of plagioclase with water shows that its content in the solution is 213 mg/L. For comparison with the data for albite, a correction is necessary because albite molecule content in oligoclase is only 77 percent. To calculate this correction, taking Morey's data as a standard, we obtain the result that one L should contain, as the result of reaction with oligoclase, 245 mg of material with the albite molecule ratios. According to our experimental data, the albite molecule present in solution amounts to 213 mg. This magnitude is very close to and permits comparison of stability of the three minerals, including microcline, for which Morey and Chen also give results. Using these, it may be said that the order of magnitude of the stability of all three minerals is close, but their most energetic reaction with water is for albite.

Numerical characteristics of transfer into solution of reacting water (mg/L) at t=350° and P=350 kg/cm^2 are: for albite, 318; for microcline, 268; and, for oligoclase, 220.

For preliminary comparison, the behavior of basic plagioclase, i. e. labradorite, under analogous conditions, experiments were carried out to study the reaction of water with labradorite (selected from rock with 97-98 percent labradorite) at 500°.

The ratio of material going into solution under experimental conditions after deduction of the anorthite portion, calculated from CaO content in the solution, corresponds here also to the albite molecule. The amount of this plagioclase component predominates significantly over the anorthite molecule. For oligoclase at 500° and at a pressure of 400 kg/cm^2, transfer into solution of the albite component is nearly in proportion to amounts required by theory.

TABLE 1. Ratio of components in solutions formed after reaction of albite and oligoclase with water, at t=350° and P=350° kg/cm²

		R_2O	Al_2O_3	SiO_2	Data of
Albite	Weight	0.64	1	3.96	Morey and Chen
Obligoclase	Ratios	0.82	1	4.0	Author
Albite		0.61	1	3.5	Theoretical
Albite	Molecular	1.05	1	6.7	Morey and Chen
Oligoclase	Ratios	1.3	1	6.9	Author

After reaction with water at t=500° and P=400 kg/cm², of oligoclase and labradorite, calculated content of the albite and anorthite portions of total mineral matter in the condensate gave the following figures, in Table 2.

TABLE 2. Albite and anorthite content calculated from total mineral matter in the condensate

	After reaction of oligoclase		Theoretical content in oligoclase, percent	After reaction with labradorite		Theoretical content in labradorite, percent
	mg/L	percent		mg/L	percent	
Albite	31.4	78	77	53.4	79.4	48
Anorthite	9.0	22	23	13.9	20.6	52
	40.4			67.3		

According to the anorthite molecule content in oligoclase, 96 percent of the anorthite went into solution under experimental conditions; but of labradorite, only 40 percent of its anorthite content. Under the same conditions labradorite yields more material to the solution than oligoclase in quantitative relations. With respect to total mineral matter in the condensate, the amount of labradorite decomposed by water was nearly twice that of oligoclase. Basic plagioclase, consequently, shows less stability than is known from observation by microscopic study of plagioclases in rocks. This characteristeristic, however, does not at all indicate the predominant transfer into solution of the anorthite component in plagioclase. At least this does not take place during reaction with water only. Presence of CO_2 probably would change the behavior of the anorthite component.

The data given afford a notion of composition of the solutions that can form with in intergranular spaces in rocks, as the result of reaction between acid plagioclase and water; they show predominant leaching of the albite component, by mobility of this solution composition under a wide range of temperature and pressure conditions.

REFERENCES

1. Khitarov, N. I., EKSPERIMENTALNAYA KHARAKTERISTIKA USTOYCHIVOSTI KVARTSA I MIGRATSII KREMNEZEMA V GIDROTERMALNYKH USLOVIYAKH [EXPERIMENTAL CHARACTERISTICS OF THE STABILITY OF QUARTZ AND THE MIGRATION OF SILICA UNDER HYDROTHERMAL CONDITIONS], In: TRUDY IV SOVESHCHANIYA PO EKSPERIMENTALNOY MINERALOGII I PETROGRAFII [VOLUME IV, CONFERENCE ON EXPERIMENTAL MINERALOGY AND PETROGRAPHY]: Izd. Akad. Nauk SSSR, M.-L., no. 2, 1952.

2. Morey, G. W., and W. T. Chen, THE ACTION OF HOT WATER ON SOME FELDSPARS: Amer. Min., no. 11-12, 1955.

AGE OF ALKALINE-ULTRABASIC ROCKS OF MAYMECHA-KOTUY REGION ACCORDING TO PALEOMAGNETIC DATA[1]

by

B. V. Gusev

• *translated by A. J. Shneiderov* •

ABSTRACT

Investigations of widely distributed negative magnetic anomaties in the Maymecha-Kotuy region (72° N. Latitude, 102° E. Longitude), showed that remanent magnetization is present in the rocks; and, that they could be subdivided into magnetically stable and unstable categories. Studies were based on 1, 600 oriented rock samples. Paleomagnetic data derived from mean directions of magnetization were used to calculate the North Polar coordinates for the time of formation for the various rocks; these data can be compared to mean values of North Polar coordinates determined for various periods. Mean values for the North Polar coordinates derived from remanent magnetization data on basic and ultrabasic rocks of the Maymecha-Kotuy region, correspond to those of Permian-Carboniferous time. No paleomagnetic age correlation was possible for magnetically unstable rocks. Results disagree with paleontological data, which indicates these rocks to have formed in late Permian to Early Triassic times; however, they are found to agree with data derived by the argon method. A correction of 20° mean value of dip in meymechites, was incorporated into the calculations with the result that the corresponding polar coordinates were 44° N. Latitude, 148° E. Longitude; and, in agreement with findings for all other rocks. Thus, meymechites probably were formed as a horizontal layer and, later, uplifted by younger intrusion of dunite-peridotite magma; and, that they are probably of effusive origin. It is believed that this method can be used eventually for more extensive determination of age correlation for various rocks and massifs. --D. D. Fisher.

***

Investigations of magnetization of the basic (?) and ultrabasic complex in the Maymecha-Kotuy region (latitude (ϕ) = 72°N, longitude (λ) = 102°E)[2] was carried out in 1956-1958 for the purpose of studying negative magnetic anomalies widely distributed in the area. Nearly 1, 600 oriented samples of magmatic rocks most typical of the region were studied. In an analysis of the magnitude and direction of natural remanent magnetization, definite regularities have been established in the distribution of remanent magnetization in the rocks; and, these rocks subdivided into magnetically stable and unstable groups. As a result of this, it was proved possible to pick out those groups of rocks whose natural remanent magnetization reflects the past magnetic field of the earth.

Data on the mean directions of remanent magnetization for some rocks, and coordinates of the earth's North Pole at the time when those rocks were formed are given in Table 1. Also, the radius of confidence computed in accordance with Sir Ronald Fisher's method described by A. N. Khramov paper [4], is given. The past positions of the North Pole have been calculated according to the formulas for a magnetic sphere uniformly magnetized [2].

The paleomagnetic data shown in Table 1 can be compared with the mean values of the North Polar coordinates determined for various periods by many European and Asian investigators (table 2).

The mean position of the North Pole, as it comes out from the remanent magnetization analysis of rocks from the Maymecha-Kotuy region, corresponds to that of the Permian-Carboniferous. The possible variations of this pole's position (error of the method considered) are not beyond the Permian period for the upper limit and for the lower limit, the Carboniferous period. Insofar as the analysis has been based on the study of traps and ultrabasic rocks, data obtained should be referred to those particular complexes that constitute the first stage of alkalic-ultrabasic formations. For magnetically unstable alkalic rocks, it was found impossible to establish paleomagnetic-age correlation.

The results arrived at do not agree with geological data. Opinions of the majority of investigators agree that the traps and the ultrabasic and alkalic intrusive rocks of Maymecha-Kotuy region are related closely by age as well as geographically; and that they were formed principally during the late Permian and Early Triassic epochs. Only the observations of A. I. Ivanov in 1956, that give evidence of the presence of basaltic tuffs in lower Permian

[1] Translated from Vozrast shchelochno-ultraosnovnykh porod maymecha-kotuyskogo rayona po paleomagnitnym dannym: Informatsionnyy Byulleten Instituta geologii arktiki; Leningrad, no. 4, 1959, p. 30-33.

[2] Board of Geographic Names coordinates.

TABLE 1. Paleomagnetic data on the position of the North Pole of the earth in ancient times.

Rock and locality	Mean direction of magnetization in the rock		Number of samples	Radius of the confidence circle (in degrees)	North Polar coordinate in the past	
	Declination (in degrees)	Inclination (in degrees)			Latitude (in degrees)	Longitude (in degrees)
Olivinites, Kugda	310	-65	194	9	N 33	E 141
Diabasic basalt, Guli	275	-64	47	10	N 41	E 169
Olivinites, Odikhincha	296	-67	43	17	N 39	E 149
Ore pyroxenites and periodites, Guli	280	-71	50	10	N 47	E 157
Ultrabasic dikes, Kotuy	272	-68	16	2	N 47	E 169
Meymechites, * Guli	305	-51	38	8	N 20	E 150
The mean for all rocks	295	-68	388	5	N 40	E 150

* The rock name 'meymechite' is incorrectly derived; according to the location, it should be: 'maymechite'.

TABLE 2. Coordinates of the North Pole of the earth for some geological periods (according to A.N. Khramov).

Period*	Mean coordinates of the north pole	
	Latitude (in degrees)	Longitude (in degrees)
Jurassic	N 59	E 163
Triassic	N 50	E 153
Permian	N 45	E 172
Carboniferous	N 38	E 130
Devonian	N 30	E 142

* The author uses the terms epoch and period interchangably.

strata determined by their flora, suggest the early Permian epoch to have been the beginning of the trap volcanism.

The significant divergence between the age-determination results for the complex of rocks considered by the two methods, i. e. the paleomagnetic and paleontologic, may arise from the fact that these methods are based on two distinctly different approaches to solution of the problem. The paleontologic method is a relative one, and does not always permit determination of absolute age for rocks. The paleomagnetic method is, in its very essence, absolute. It would be interesting, therefore, to compare its data with absolute-age-determination results for alkalic-ultrabasic rocks of the Maymecha-Kotuy region, carried out by G. G. Moor (e). The age of mica from various intrusive massifs, obtained by the argon method, averages 250 million years, corresponding to the early and middle Carboniferous.

Thus, paleomagnetic data agree with the results of another absolute-age-determination method for rocks; and they diverge from data derived by the paleontologic method. In this connection, speaking of the substantial difference between the age determinations for rocks of the area, it is quite sensible to put forward the following query: Does not the paleontologically established Permian-Triassic period correspond to the Permian-Carboniferous by absolute-age-determination? In solution of this problem, a significant part should be allotted to paleomagnetic investigations.

The paleomagnetic data shown in Table 1 make possible consideration of the genesis and relative age for meymechites found within the boundaries of the Guli massif, representing a layer dipping 10 to 30° to the North. T. D. Goldburt and L. S. Egorov believe that the meymechites were emplaced in the second intrusive phase (following the dunites and peridotites). Analogous views were expressed earlier by Yu. M. Sheynmann and Ya. I. Polkin. E. D. Butakova holds to the opinion that the meymechites formed prior to the Guli intrusion were of effusive origin [1].

One can see from Table 1 that the inclination of the mean remanent-magnetization vector is much smaller in meymechites compared to that in other rocks. This difference is distinguished even more prominently in the North Pole coordinates. If, however, in the direction of meymechites' remanent magnetization, a correction is introduced for the dip of meymechites, taking 20° for its mean value, the pole coordinates are found to be latitude = 44°N, longitude = 148°E; this is in good agreement with its mean position according to all other rocks, and to those as well, that are

spatially closest to meymechites, i.e. ore pyroxenites and peridotites, and diabase basalts. It may be considered then, that the meymechites represented a horizontal (or nearly horizontal) layer at the moment of their formation, and were uplifted merely by the subsequent intrusion of dunite-peridotite magma. In such a case, it is natural to recognize the younger age of the dunite-peridotite intrusion. It appears also that these data attest to effusive origin of the meymechites.

Examples of the paleomagnetic-data analysis discussed indicate the value of this new method for geological investigation of the Maymecha-Kotuy region.

Undoubtedly, utilization of this method on a wider scale would result in sufficiently accurate age-correlation determinations for various rocks and massifs, and would elucidate a number of other geological problems.

REFERENCES

1. Butakova, E. L., K PETROLOGII MAYMECHA-KOTUYSKOGO KOMPLEKSA ULTRAOSNOVNYKH I SHCHELOCHNYKH POROD [ON THE PETROLOGY OF MAYMECHA-KOTUY COMPLEX OF ULTRABASIC AND FELSIC ROCKS]: Trudy Inst. Geol. Arktiki, v. 89, 1956.

2. Komarov, A. G., OSTATOCHNOYE NAMAGNICHENIYE GORNYKH POROD I IKH VOZRAST (PALEOMAGNETISM I DVIZHENIYE POLYUSOV) [REMANENT MAGNETIZATION OF ROCKS AND THEIR AGE (PALEOMAGNETISM AND MOVEMENT OF THE POLES)]: Izv. Akademiya Nauk SSSR, Ser. Geol., no. 10, 1957.

3. Moor, G. G., O VOZRASTE ULTRAOSNOVNYKH I SHCHELOCHNEKH POROD SEVERA SIBIRSKOY PLATFORMY [ON THE AGE OF ULTRABASIC AND FELSIC ROCKS OF THE NORTH OF THE SIBERIAN PLATFORM]: Inf. Byull. Inst. Geol. Arktiki, Leningrad, no. 8, 1958.

4. Khramov, A. N., PALEOMAGNITNAYA KORRELYATSIYA OSADOCHNYKH TOLSHCH [PALEOMAGNETIC CORRELATION OF SEDIMENTARY STRATA]: Gostoptekhizdat, 1958.

MIGRATION AND ACCUMULATION OF OIL AND GAS ACCORDING TO THE SOURCE-ROCK THEORY[1]

by

I. O. Brod[2]

• *translated by the author* •

ABSTRACT

Practically all oil and gas accumulations throughout the world are associated with some extensive productive series which consist of highly permeable rocks containing oil and gas pools, interbedded with shales and marls containing dispersed organic matter. All of the important recent discoveries between the Volga and the Urals were based on the observed association of oil and gas pools with certain lithologic-stratigraphic complexes of the Devonian, Carboniferous, and part of the Permian; although accumulation is related to many diverse structural zones. Here, the productive series is the source rock as well, for the pelites contain dispersed organic matter including bitumen whose composition is related to the oils.

Where accumulations occur in sediments deposited under oxidizing conditions, factors are sought which favor migration from possible source rocks along faults, unconformities, or surfaces of facies change. For example, in Azerbaidjan and Turkmenistan large oil and gas accumulations in Pliocene continental beds occur along structural zones that allowed migration from underlying, principally Paleogene and Miocene, deposits.

As shales compact, their organic constituents gradually change; the coaly part from a ligniferous to a carboniferous stage and, ultimately, to graphite. The mobile bituminous substances formed by dissociation of organic matter and disproportioning of hydrogen, change from asphaltines and resins to oils and then to methane in the subcapillary pores of pelites, where they are in a dispersed, loosely bound state. Compaction causes slow removal of the loosely bound water and molecular migration with differentiation of the bituminous substances. After differentiation, the more mobile hydrocarbons are carried by the water into reservoir rocks. The bituminous substances move from small to large pores also by capillary forces. Migration in subcapillary pores apparently ceases when rocks become lithified and are no longer plastic.

In the super-capillary pores and fissures of reservoir rock, free migration takes place as both molecular migration and movement in larger masses. Water circulates in reservoir beds from elevated areas of the outcrop toward lower discharge areas. When the hydrocarbon-bearing water moves into different environments of temperature and pressure, the hydrocarbons may come out of solution, rise to the top of the carrier-beds, and unite into oil and gas pools if traps are available. The location of oil and gas reflects the present equilibrium of fluids with the structural pattern and hydrogeological environment. --D. C. Van Siclen.

* * *

The phrase "oil and gas accumulations" includes all categories, from individual pools to groups of pools, both in the subsurface of separate areas as well as within extensive regional oil-and-gas-bearing zones (Brod [80, 10, 11, 15, 24], Vassoyevich and Uspensky [25] and Khain [75].

When examining closely the conditions of formation of oil accumulations, as far as single accumulations (pools) are concerned, the principal task consists of elucidating how the hydrocarbon compounds entered the trap containing the pool.

The analysis of conditions leading to formation of an oil field embracing a number of pools in the subsurface of a common area and controlled by a single structural element is far more complicated. It is necessary, in the first place, to determine the geological and hydrogeological environment during the structural deformation which caused development of the numerous traps. Next, it is necessary to ascertain the relationship of the traps when they

---

[1]Translated from : Problema formirovaniya skopleny nefti i gaza v svete teorii neftematerinskikh svit: In, Problema migratsii nefti i formirovaniya neftyanykh i gazovykh skopleny (Problem of oil migration and formation of oil and gas accumulations): Materialy Lvovskoy diskussii 8-12 May 1957, Akademiya Nauk SSSR, Institut Geologii poleznykh iskopayemykh, Moscow, 1959. Submitted by George V. Chilingar.

[2]Moscow, Chair of geology and geochemistry of mineral fuels (?) Lomonosov University of Moscow, and USSR, Academy of Sciences, Oil Institute.

were being filled by the hydrocarbon compounds. Practically, the task is that of studying the conditions of migration and differentiation of mobile substances in the different reservoir beds and in poorly permeable rocks separating the reservoirs, both of which make up the stratigraphic sequence of oil fields.

In order to analyze the conditions of formation of oil-and-gas-bearing zones, it is necessary to ascertain the sequence and correlation of geological, geochemical, and hydrogeological processes which help to form the numerous oil and gas accumulations systematically distributed in the subsurface of large areas of the earth's crust. During the last few years these processes have been elucidated thoroughly in several countries in numerous publications devoted to the regional hydrogeological environment and to the conditions of formation of separate oil fields and extensive oil and gas accumulation zones (Ignatovich [40], Brod [13, 15, 24], Lindtrop [46], Sukharev [66], Vassoyevich and Uspensky [25], Krems [43], Bakirov [7], Lalicker [100], Beeby-Thompson [77], Gussow [88, 90], Hobson [91], and many others).

The problem of how oil and gas accumulation zones form is closely related to the problem of petroleum origin; for the formation of these zones results from generation and migration of petroleum constituents in the earth's crust. Consequently, to study the conditions of formation of zonal accumulations it is necessary to determine regularities in occurrence of oil and gas accumulations in the earth's crust.

REGIONAL PRODUCTIVE FORMATIONS AND SOURCE ROCKS

It may be considered to be an established fact that in practically all oil and gas basins of the world the accumulations are related to some extensive regionally productive series. The latter are known to occur in deposits of different ages and to contain over broad areas either natural oil and gas seeps or oil and gas pools discovered by drilling. Most regionally productive series consist of highly permeable rocks that contain oil and gas, interbedded with shales and marl that contain dispersed organic matter.

Widely distributed oil seeps related to bituminous rocks are known in the Cambrian of the east Siberian platform; and, to a considerably lesser degree in Canada gas accumulations are related to the Cambrian of the Appalachian trough.

Large oil and gas pools related to sandy marl and carbonate rocks of the Cambrian-Ordovician and, to a lesser degree, to those of Silurian, are known in the central part of the North American platform. The bituminous rocks and oil and gas seepages in the Baltic region of the Russian platform are related to similar lithological-stratigraphic complexes of the lower Paleozoic.

Still more widely distributed oil and gas pools and seeps occur in a number of lithologic and stratigraphic complexes of Devonian and Carboniferous age, and partly in the Permian, in the central parts of the Russian and North American platform.

On the edges of the Russian, North American and East-Siberian platforms as well as in several intermontane troughs of Eurasia and of North and South America, some lithologic-stratigraphic complexes of the Jurassic and Cretaceous are regionally productive.

Oil and gas pools as well as seeps are well known in clastic carbonate complexes of Paleogene, Miocene, and Pliocene age in piedmont basins along young folded mountain ranges and in a number of intermontane troughs of Eurasia, Oceania, and North and South America. Oil pools in formations of the same age in the deeply subsided southern part of the North American platform are known as well.

The data on this matter can be found in numerous summaries published during the last few years (Beeby-Thompson [77], Landes [101], Russell [109], Illing [96], Levorsen [104], Brod and Eremenko [21], and others).

In the early development of the oil industry, at the close of the nineteenth and the beginning of the twentieth century, several researchers were of the opinion that oil accumulated in reservoir rocks by migration from silty sediments. The generation of hydrocarbon compounds has been connected by the previously mentioned scientists, with transformation of organic substances dispersed among the small mineral particles composing shales and marls. For the Caucasian petroliferous areas these ideas were formulated principally in the works of N. I. Andrušov [2] and G. M. Michailovsky [53]. The development of these ideas in other countries can be found in several special summaries (Höfer [92], Campbell [81], De Launay [102], Bogdanovitch [9], Blumer [79], and others).

Subsequently, the relationship between oil formation and dispersed organic matter has been developed in the U. S. S. R. through special investigations; a number of general conclusions have been published by A. D. Arkhangelsky [4], I. M. Gubkin [34, 36, 37] and their numerous followers.

The status of this problem in other countries is elucidated in a series of fundamental works (Lilley [105], Graf-Krejci [98], Emmons [86], Stutzer [113], De Cizancourt [82], Macovei [106], Trask and Patnode [115], and others.)

Arkhangelsky [4], based on extensive collective study of the oil fields of Europe and America over several decades, noted that: ". . . for numerous oil fields it is well ascertained that the oil is related to those sedimentary series containing rocks rich in organic matter of the petroleum type, the so-called bituminous shales, oil shales and limestones." He stated further: "It is quite natural that many researchers have been confronted with the question: what are the conditions under which these bituminous rocks formed, conditions which also might determine to a great extent process of oil formation."

The series in which oil and gas formed and accumulated by transformation of dispersed organic matter contained therein, have been called by Arkhangelsky, Gubkin and their followers "primary oil-bearing series." Rocks containing dispersed organic matter which under favorable conditions can be transformed into petroleum, were called "nefteproizvodyatshchiye" (oil producing) or "neftematerinskiye" (source rocks). In the foreign literature these rocks are termed "source rocks" or "source beds" in English; "roches-mère" in French; and "Ölmuttergesteine" in German.

All important discoveries of oil and gas zones in the Caucasus and on the Russian platform in the U. S. S. R. were made on the basis of ascertained regularities in occurrence of oil and gas pools in regional petroliferous series.

All recent discoveries in the vast territory between the Volga and the Urals, which increased by many times the oil production in the Soviet Union, were made on the basis of ascertained regular relationships between oil and gas pools and certain lithologic-stratigraphic complexes of the Devonian, Carboniferous, and part of the Permian. The productivity of these complexes is related to numerous and diverse structural zones (Brod [14], Bakirov [6], Trofimuk [69], Mirchink [56, 57], Mustafinov [58, 59], and others).

Taking into consideration the well-established relationship between oil and gas pools and definite intervals of the Mesozoic-Cenozoic sequence, and based on lithologic, stratigraphic, and tectonic similarities, we could predict for the territory adjacent to the Eastern Caucasus the known and possible oil- and gas-accumulation zones which have been proved by subsequent drilling (Brod [14, 19, 23], and Alexin [1]).

In the Volga-Ural region and in the region adjacent to the Caucasus, oil and gas pools are contained most frequently in reservoir beds between pelitic rocks that contain dispersed organic matter including bitumens whose composition is related to the oils. In these cases, oil-and-gas-bearing series also can be considered as the source rocks. In other cases, we have to look for the oil source material outside the productive formation. Thus, for example, presence of rich oil and gas pools in dolomitic limestone should be related to clay-marl strata either mantling or underlying the dolomite series, or in contact with it along a surface of facies change or unconformity (Brod, Tsaturov, Nesmeyanov [23]).

In continental deposits of the intermontane troughs of Middle and Central Asia, which formed in an oxidizing environment, oil and gas seeps and pools usually are associated with those parts of the stratigraphic sequence containing dark-colored, subaqueous pelitic strata which were deposited under reducing conditions.

Using a number of properties characterizing source beds, and the relationship of source rocks to reservoir rocks, several authors attempted to segregate intervals of the sequence favorable for oil and gas accumulation both in various districts of the U. S. S. R. (Ulianov [70], Uspenskaya [72], Brod [16, 19, 22, 23], Vassoyevich and Uspensky [25], Trofimuk [69], Maximov [48], Konyukhov[42], Bakirov [8], Dvaly and Drobshev [38], Maymin [47], Mekhtiyev [52], Mirchink [57], Geologichesky Sbornik no. 1, [29], and Geologichesky Sbornik no. 2 [30], as well as in other countries (Van Tuyl [116], Wilcox [118], Gussow [90], Hobson [91], and many others).

In those regions where oil and gas accumulations are related to a series deposited under oxidizing conditions unfavorable for transformation of dispersed organic substances into bitumens, particular attention is focused on finding factors favorable for formation of oil and gas pools by migration from other possible source rocks. Thus, for example, in Azerbaidjan and Turkmenistan large oil and gas accumulations in a Pliocene productive series of continental origin are related to structural zones allowing vertical migration of hydrocarbon compounds from more ancient source beds. (Gubkin [35], Gorin [31], Mekhtiyev [52], and others). In this case, important oil and gas zones contain numerous oil fields formed by migration of hydrocarbon compounds mainly from Miocene and Paleogene deposits underlying the productive series.

Although some researchers (Kudryavtsev [44], Porfiryev [61, 62]) allege that the theory of the origin of petroleum from dispersed organic matter is currently at a deadlock; in fact, during the last 10-15 years much more was done to develop this theory than during the preceding 60 years.

In recent years it has been proved that dispersed organic substances related to petroleum are contained in certain quantities in practically all argillaceous, shale-arenite, sandy shale and marly rocks formed in a reducing environment (Eremenko, Maksimov

and Tkhostov [39], Strakhov and Rodionova [65], Teodorovich [67, 68], Yurkevich [74], Brod and Levinson [20], Sbornik "Proiskhozhdeniye nefti [60], Geologichesky Sbornik [30], Konyukhov [41, 42], Vassoyevich [26], Maymin [47]). Bituminous substances related to petroleum have been found not only in the consolidated rocks, but also in Recent and Quaternary subaqueous sediments. Transformation of these bituminous substances during compaction of the sediments into substances more and more like petroleum hydrocarbons was ascertained at the same time (Weber [27], Smith [111, 112]).

The process of dissociation of organic substances is observed in the appearance of new bituminous compounds formed apparently at the expense of hydrogen disproportion (Brod and Mekhtiyev [18], Geologichesky Sbornik no. 1 [29], Geologichesky Sbornik [30], Brod and Eremenko [21], Vassoyevich [26]). It may be surmised that in the process of compacting the pelitic rocks there is gradual metamorphism of all their constituents and, in the first instance, regular change in the predominant coaly part and, as well, in the accompanying bituminous part. Transformation of the coaly part of the dispersed organic matter goes from a ligniferous to a carboniferous stage and as far as graphite. To all appearances this process is accompanied by the formation in subcapillary pores of new bituminous compounds increasingly rich in hydrogen. Comparison of the elementary and component composition of bituminous substances dispersed in the subcapillary pores of pelitic rocks with petroleum saturating the supercapillary pores of the reservoir rocks leads to the twofold conclusion that there is a genetic resemblance, but that at the same time there are numerous differences depending on the physicochemical state of these substances. Therefore, formation of petroleum possessing distinctive properties should be related to a process of transformation from the bituminous substances dispersed in subcapillary pores in a loosely-bound state, into the mutual solution of hydrocarbons, resins, and asphaltines in the water-saturated reservoir rocks which accumulated subsequently as oil and gas in traps (Fash [87], Brod [15, 18, 21], and Weber [27]).

On the basis of ascertained regularities in the relationship of source rocks and reservoir rocks, attempts have been made during the last few years to segregate cycles of bitumen formation corresponding to the source rocks and the regionally productive lithologic-stratigraphic complexes (Eremenko, Maksimov, and Tkhostov [39], Brod [15], and Konyukhov [41, 42].

Analysis of regularities in the regional changes of lithology and thickness of lithologic-stratigraphic complexes favorable for oil and gas accumulation provides an opportunity to map to a first approximation the oil and gas possibilities of each and every separate rock complex; this was done, for example, in 1955 for the territory adjacent to the Eastern Caucasus (Brod [23]).

The overwhelming majority of the more important oil and gas accumulation zones discovered in the U.S.S.R., North and South America, and recently in the Near and Middle East, is connected with regions of stable downwarping or subsidence of the earth's crust. In the sequence of these regions, an important place is occupied by lithologic-stratigraphic complexes which can be considered as source rocks (Howard [93], Pratt [107, 108], Kaufmann [97], Brod [15], and others).

The doctrine of source rocks and regionally productive series, born at the end of the last century, has been gradually transformed into a consistent theory. This theory allows one to make well-founded predictions and comparative estimates of the oil and gas possibilities of large territories and of the different oil and gas accumulation zones within them.

REGIONAL CONDITIONS OF OIL AND GAS ACCUMULATION

Although the early studies of the classification of oil and gas accumulations (Clapp [83, 84], Gubkin [34], and others) did not formulate distinctly the concept of "zonal occurrence of oil and gas accumulations"; their descriptions of separate groups of accumulations already contained this concept.

Until the third decade of the 20th century, scientists had concentrated their attention and efforts on learning the relationship between numerous oil and gas accumulations and anticlinal zones.

A. I. Levorsen [103] has formulated in a most distinct manner the concept of regular zonal occurrence of numerous oil and gas traps on the flanks of large downwarped areas of the earth's crust. At the same time, Levorsen has contrasted the structural factor of oil and gas accumulation to the stratigraphic traps that occur as a result of lithologic wedging-out or unconformable overlapping of the productive series at the up-dip edge.

The principle of division of productive zones into two genetic groups, i. e., structural and stratigraphic, has justified itself.

In 1937 Gubkin formulated a principle that, for anticlinal zones with which numerous oil and gas fields are associated, the adjacent synclinal depressions served as oil and gas source areas (Gubkin [36]).

The concept of oil and gas accumulation zones in petroleum literature (Brod [10]) is related intimately to the concept of oil and gas source

areas. Taking into consideration that in the more downwarped areas of the earth's crust the pelitic rocks are under a higher pressure compared with uplifted areas, it should be surmised that differentiation of bituminous substances and movement of the more mobile particles into carrier beds should proceed in the direction from the oil and gas source area towards the oil and gas accumulation zones.

When bituminous substances migrating in the subcapillary pores of pelitic rocks reach the highly permeable reservoir rocks they enter into close contact with the water freely circulating in these rocks. In the process of differentiation of the mobile substances in reservoir rocks they are separated into either oil with gas or pure gas, with formation of pools in separate traps. Numerous traps filled with oil and gas form the fields which constitute the oil and gas accumulation zones (Brod [10, 15, 24]).

The problem of regional differentiation of oil and gas in natural reservoirs and their accumulation in numerous traps has been thoroughly studied by W. C. Gussow, a Canadian researcher who has worked out a consistent theory of differential entrapment and accumulation. His theory relates a number of regularities in the distribution of pure gas pools, oil pools with gas cap, and pure oil pools in various traps in the same reservoir bed (Gussow [88]). Some principles of this theory have been subjected to criticism in a special discussion, the proceedings of which were published (Discussion [85]). It has been argued that the general regularities emphasized by Gussow may take place only in a perfectly ideal case. Regular relations noted by the present author show that these are likely to be altered by a change in dip of the strata, by an increase or decrease in depth of burial, and by inflow of oil from depth along faults and fractures. At the same time, there is no disagreement that oil and gas pools do result from the process of differentiation of the fluids at the time of their migration in rocks of high permeability.

In the zones of structural accumulation, feeding by hydrocarbon compounds usually takes place from two sides. The petroleum substances migrate from synclinal depressions to the most uplifted parts of brachyanticlines and domes, which are the components of anticlinal zones, and accumulate into oil and gas pools either in the crests of anticlines or in screened traps on their flanks or periclines.

The case proves to be somewhat different for bituminous substances that feed into zones of stratigraphic oil and gas accumulation consisting of numerous traps on homoclines or monoclines caused by regional lithologic wedging-out or unconformity. Hydrocarbon compounds coming up the regional dip accumulate in separate traps of the most varied shape, which are grouped along the wedging-out or unconformably overlapped edges of the reservoir rocks. The feeding here is one-sided, for the downdip parts of the same homoclines and monoclines serve as the oil and gas source areas.

Numerous examples of such accumulation conditions are quoted in Levorsen's publications [103, 104] and many others. In the U. S. S. R., a similar zone of oil and gas accumulation in the Maikop Oligocene petroliferous formation is well studied in the Krasnodar region, at the western part of the northern side of the Caucasus (Gubkin [33, 36], Khelkvist [76], Ulianov [70]). Large oil pools in the wedging-out zones in the lower strata of the Pliocene productive series in the Apsheron peninsula similarly characterized by one-sided hydrocarbon feeding (Mirchink [54, 55], Gorin [32], Mekhtiyev [51, 52], and Baba-Zade [5]).

In order to elucidate conditions of formation of oil and gas accumulation zones within large territories, it is necessary to ascertain regularities in the occurrence of these zones and of their related source areas. American geologists (Woodruff [119], Schuchert [110], Lilley [105] and Ver Wiebe [117]) introduced into the literature in the first quarter of this century the term "oil and gas province" and, less often, "oil-bearing province" ("neftegasonosnaya provintsia").

N. Yu. Uspenskaya [71] defines this term as follows: " An oil and gas province is a large territory in which the oil and gas accumulations possess unity of geologic structure and geologic history, characterized by uniform facies and types of structural elements controlling bitumen formation and oil accumulation. " Based on such a definition N. Yu Uspenskaya considers oil bearing provinces to consist of: 1) depressions of different ages; 2) large arched uplifts; and 3) uplifts on the slope of large structures, etc.

In view of the extreme indefiniteness of this term, and its quite frequent use with different meanings by various authors, including the American geologists who suggested it, we would prefer to abandon it.

Analysis of regularities in occurrence of presently-known oil and gas accumulation zones proves these to be parts of large downwarped areas in the basic structural pattern of the earth's crust. Regional hydrogeological investigations have proved that the location of feeding and discharge areas within rocks of high permeability determines the direction of water flow in these rocks which serve as reservoirs for mobile substances. The circulating water is saturated to a certain extent with various salts and, frequently, with organic acids. Hydrocarbon compounds in small concentrations are frequently

found to be dissolved in this water. With changes in temperature and pressure, the hydrocarbon compounds separate from water and accumulate in the traps as oil and gas pools, provided traps are present.

The formation and preservation of oil and gas accumulations in local traps is determined principally by the regional hydrogeological environment. Occurrence of numerous accumulations in oil and gas accumulation zones is related closely to the present structure of thick series of sediments inclosing these accumulations. The regular relationship between known oil and gas accumulation zones, and the various types of large downwarped regions of the earth's crust has served as a basis for terming such depressions oil and gas basins (Brod [17]). Each oil and gas basin is a vast artesian basin; the location of oil and gas accumulation zones within its confines reflects the present equilibrium of liquids and gases saturating reservoir rocks under the present structural pattern and regional hydrogeological environment.

Conditions of oil and gas accumulation and preservation should be examined independently for each basin.

All known oil and gas basins are divided by us into three main groups on the basis of their geotectonic nature and conditions of oil and gas accumulation: 1) Basins related to troughs of platform areas beneath plains; 2) basins of intermontane troughs; and 3) basins related to piedmont depressions of the young folded mountains.

A thorough study of the formation conditions of oil and gas accumulation zones is possible only when we take into consideration all changes undergone by that certain area of the earth's crust throughout its geologic history. Whether the relationship between reservoir rocks of high permeability and those of poor permeability (pelitic rocks) is most favorable for oil and gas accumulations can be determined only if one has adequate knowledge of the regularities in changes of thickness and lithology of the sedimentary series forming the basin. But, on the other hand, whatever changes the area has undergone in its geologic past, the decisive factor determining the present location of the oil and gas accumulation zone is the present position of the zone within the downwarped region or oil and gas basin. Such a presumption is based upon the fact that formation of the individual oil and gas pools, which make up the oil and gas accumulation zones, takes place by the process of migration and differentiation of mobile substances in the highly permeable rocks which serve as their natural reservoirs. Formation and preservation of each and every separate accumulation is possible only in traps that do not allow the oil and gas to escape. Preservation and refilling of oil and gas pools are possible only in cases where the traps have remained intact until the present time. Any change in shape of the trap or in regional hydrogeological environment may lead to the destruction of some pools or, at least, to their redistribution.

Present oil and gas accumulations reflect the existing equilibrium of the mobile substances contained in oil and gas basins.

ROLE OF DIFFERENT TYPES OF MIGRATION IN THE FORMATION OF OIL AND GAS ACCUMULATIONS

Separate pools as well as large oil and gas accumulation zones form in the course of migration and differentiation of the substances composing oil and gas.

Migration has been studied by many researchers throughout the period of development of the science of petroleum. Summarized data, status of the problem, and classifications of migration processes have been published on by Lilley [105], Graf-Krejci [98], Gubkin [34], Lahee [99], Bloesch et al, [78], Illing [94, 95], Van Tuyl, Parker, Skuters [116], Brod [12, 15, 20, 21], Zalicker [100], Landes [101], Vassoyevich and Uspensky [25], Krems [43], Gussow [88, 89], Bakirov [7], Linetsky [45], and Sokolov [64], Hobson [91], and in many other books devoted to petroleum geology.

An attempt to systematize all known data on migration of bituminous substances, gas, petroleum and its derivatives in thick series of sediments and in particular strata has been made by us after Illing, Lahee, Krejci-Graf and Bloesch in 1947-1951. This attempt has resulted in working out of a classification of migration processes according to distance and character of movement (table 1) and according to ways and direction of movement (table 2). Migration in the source rocks remains the least studied problem today.

Slow molecular migration of loosely-bound mobile substances goes on in the subcapillary pores of pelitic rocks. Among these substances water, and bituminous materials interacting with it, are of the most importance. Outcropping folded sedimentary strata are fed by atmospheric water, which circulates in the supercapillary pores of the permeable carrier-beds serving as natural reservoirs for the mobile substances. Water circulates from elevated areas of outcropping strata (intake areas) toward the downdip direction. Speed of circulation is not uniform in different parts of the flow.

The circulating water carries away bituminous substances escaping from the pelitic rocks. Differentiation of the mobile substances according to their specific gravity proceeds much more easily during movement. Hydrocarbon compounds escaping from the water and rising to the

TABLE 1. Classification of migration processes according to character and distance of movement

<table>
<tr><th>Main groups of migration processes according to distance of movement</th><th>Main types of migration according to character of movement</th><th>Molecular (diffusive-film) migration</th><th>Free migration</th></tr>
<tr><td rowspan="4">Local Migration</td><td rowspan="2">Controlled by structural features</td><td colspan="2">In the confines of separate structural uplifts</td></tr>
<tr><td colspan="2">In connection with local faults on monoclines and homoclines</td></tr>
<tr><td rowspan="2">Controlled by stratigraphical features</td><td colspan="2">In connection with local lithological changes of the rocks</td></tr>
<tr><td colspan="2">Along the surface of discordance provoked by local stratigraphic unconformity</td></tr>
<tr><td rowspan="5">Regional Migration</td><td rowspan="3">Controlled by structural features</td><td colspan="2">In connection with regional dip of strata</td></tr>
<tr><td colspan="2">In connection with anticlinal zones of regional importance</td></tr>
<tr><td colspan="2">In connection with regional fractures</td></tr>
<tr><td rowspan="2">Controlled by stratigraphical features</td><td colspan="2">Along the surface of discordance provoked by regional stratigraphic uncomformity</td></tr>
<tr><td colspan="2">In connection with zones featured by regional changes of facies</td></tr>
</table>

TABLE 2. Classification of migration processes according to ways of movement

<table>
<tr><th>Group</th><th colspan="2">Extra-Reservoir Migration (in poorly permeable rocks)</th><th colspan="2">Intra-Reservoir Migration (in highly permeable rocks)</th></tr>
<tr><td>In relation to rock series in which migration takes place</td><td>Syngenetic (in sediment where accumulation and transformation of organic substances take place)</td><td>Epigenetic (through heterogeneous thick rock series)</td><td>Intra-strata</td><td>Within thick series of sediments consisting of many highly permeable strata</td></tr>
<tr><td rowspan="2">According to type of way of movement</td><td rowspan="2">Along subcapillary pores (subcapillary)</td><td>Along capillary pores (capillary)</td><td colspan="2">Porous</td></tr>
<tr><td>Along fractures and fissures (fissured)</td><td colspan="2">Fissured</td></tr>
<tr><td rowspan="2">According to direction of movement</td><td colspan="4">Lateral</td></tr>
<tr><td colspan="4">Vertical</td></tr>
</table>

top of the carrier-beds combine together into oil and gas accumulations if traps are available.

Solubility of hydrocarbon compounds in water varies with their composition, temperature, and pressure. Water that dissolves hydrocarbons at certain temperatures and pressures, may release them as it moves into a different environment. This is how bituminous substances migrate when they are dissolved in water. Also, water may force bituminous substances out of the fine pores into the large ones by capillary pressure. The mechanics of migration of hydrocarbon compounds under the action of capillary forces have not been studied adequately yet. The magnitude of capillary pressure depends on the properties of mobile substances filling the pores, on the properties

of mineral matter, and on size of the pores. Movement of bituminous substances under the action of capillary forces is always directed from the pores towards the large ones. Since capillary forces in the fine pores surpass considerably the gravitative forces, the resulting movement may not only be upwards but in a lateral direction as well. We may surmise that bituminous substances in the fine pores move as molecular films.

Any movement of mobile substances, including bituminous substances, in the subcapillary pores of source rocks can be considered as a molecular syngenetic migration. The same movement in subcapillary pores of strata other than source rock is epigenetic molecular migration.

The movement of mobile substances in supercapillary pores and fissures can be considered as free migration of water and hydrocarbon compounds related to it. Free migration proceeds in accordance with the laws of percolation of mobile substances in supercapillary pores of highly permeable rocks. In contrast to molecular migration, considerable masses of substances move together in free migration. Depending on its distance, this process may be either of local or wide regional importance.

Formation of a single oil field is related to migration of local importance. This term includes processes confined to the limits of a single structural element controlling the formation of a particular field that consists of several pools, or of one pool only.

Regional migration is the process that forms a group of oil fields systematically related to one or several oil and gas accumulation zones. Regional migration that embraces large basins can lead to formation of numerous oil and gas accumulation zones in a single oil and gas basin.

Any movement of mobile substances in rocks possessing supercapillary pores and fissures can be considered intra-reservoir migration. The movement of mobile substances through subcapillary pores and gaping fissures in poorly permeable rocks separating the natural reservoirs, can be considered as extra-reservoir migration. In intra-reservoir and extra-reservoir migration mobile substances can move in both vertical and lateral directions.

Numerous publication are devoted to the study of forces which cause intra-reservoir and extra-reservoir migration.

Any mobile substance in the pores of a sediment during deposition either should enter into the composition of the rock or migrate out of it as soon as the sediments begin to compact. Mobile substances in compacting sediments move in the direction of reduced pressure. During compaction the free water and substances related to it are carried away first. More important for bitumen formation and oil and gas accumulation is the later migration accompanying continued compaction of the sediments as they become consolidated. The size of subcapillary pores diminishes constantly during compaction of pelitic rocks, which causes a slow removal of loosely-bound water. In all probability the most mobile organic compounds are removed at the same time.

It may be supposed that all of the important transformations of organic substances contained in pelitic rocks take place in the process of migration in subcapillary pores. During compaction of pelitic rocks, slow metamorphism and dissociation of organic matter goes on at the same time. Dissociation appears to be accompanied by disproportioning of hydrogen, with the generation of more stable coaly compounds one one hand, and on the other hand, of mobile bituminous particles which moved away with the loosely bonded water.

In the process of subcapillary migration, the principal coaly part of the dispersed organic substances changes towards coalification; formation of graphite represents the last stage of its metamorphism. Bituminous substances formed by the hydrogene enrichment process should change from asphaltines and resins towards oils and on to methane. To all appearances the most mobile substances, after differentiation, are carried along with some of the loosely-bonded water into reservoir rocks, if any are present near by. Such is the probable itinerary of migrating bituminous substances; first, in the course of syngenetic migration in subcapillary pores and, later, in the course of free migration together with water in the natural reservoir beds towards the trap where the oil or gas pool forms. Oil and gas pools in reservoir rocks enclosed by rocks of low permeability form principally by migration of hydrocarbons from subcapillary pores of pelitic rocks into supercapillary pores of reservoir rocks. It should be noted that extra-reservoir migration of mobile substances in subcapillary pores is related closely to compaction; and apparently occurs only until lithification; that is, while the rocks are still plastic.

Free extra-reservoir migration through heterogeneous rock sections is related to movement of large masses of mobile substances from areas of higher pressure along gaping fractures and fissures. Water masses may entrap in their flow bituminous substances in gaseous and sometimes in liquid state and carry them from source rocks to overlying reservoir rocks.

Water movement is of principal importance in intra-reservoir migration of hydrocarbon compounds into traps. Differentiation of mobile substances in reservoir beds takes place during migration of water and bituminous compounds

dissolved therein. Separation of free gas and liquid oil may take place only under conditions favorable to their accumulation in a trap.

Thus, enroute to each pool the bituminous substances first undergo molecular migration in subcapillary pores and thereafter, free migration in the reservoir beds in the direction of the trap. The oil and gas pool forms when the hydrocarbon compounds accumulate in a trap.

From the above it appears that migration is one of the main processes of oil and gas formation as well as of accumulation, and that oil and gas accumulation zones result from the different types of migration of mobile substances enumerated above.

CONCLUSIONS

In conclusion,it should be noted that geologists, geochemists, physical chemists, mathematicians, and physicists of the whole world have made enormous contributions toward solution of problems on the formation of oil and gas accumulations.

This of course does not mean that all questions are solved; nevertheless, an enormous amount of work has been done, for in many large geosynclinal and platform regions it has been ascertained which rock series are related regionally and genetically to oil and gas accumulations. We can discuss today the specific geological and geochemical environment which formed these rock series containing oil and gas pools as well as tremendous quantities of dispersed organic matter. Today the petroleum-, gas-, and water-saturated reservoir rocks in which the pools formed are being studied. Also, the reservoir properties and mineralogical composition of the rocks forming the reservoirs, as well as the composition of low permeability rocks surrounding them, are being investigated. In the latter, the basic properties of dispersed organic substances and the geochemical characteristics of rocks are being studied.

The existence of free oil and gas as pools in reservoir rocks forming natural receptacles is beyond any doubt. Free migration of water, oil, and gas is ascertained by direct observations. As an example of such migration may be cited abundant oil and gas seeps known in mountain and piedmont regions throughout the world. This phenomenon is explained by the fact that in strongly disturbed regions there exist numerous fissures and fractures in facilitating oil and gas migration. In less disturbed regions lacking extensive oil and gas seeps, migration of mobile substances in the subsurface goes on at the same level more or less actively. Migration and redistribution of mobile substances, i. e., gas, oil and water, inside natural reservoirs is proved by their regular arrangement in order of specific gravity in highly permeable strata separated by shales of low permeability. This phenomenon is related to the regular association of oil and gas pools with traps; the latter, associated with local structural elements which form oil fields grouped into oil and gas accumulation zones.

One of the principal questions to be solved is that of the genetic kinship between oil and gas accumulated in traps and the bituminous substances in the subcapillary pores of rocks considered as source rocks. Solution of this problem will require not only a thorough laboratory study of the organic matter dispersed in rocks, but a study of its transformations as well. When carrying out such investigations it will be necessary to construct in the laboratory a simulated environment closely resembling that in which the natural physicochemical transformations undergone by the mobile bituminous substances take place. These consist of different kinds of asphaltines, resins, and oils, in the course of their transfer from the dispersed molecular state in subcapillary pores of pelitic rocks into supercapillary pores of reservoir rocks saturated with free water. Notwithstanding a number of similar features, the light bituminous substances extracted from pelitic rocks differ from the oil which forms pools in reservoir rocks. This is quite natural as the physicochemical changes of the substances proceed in a different way in the subcapillary pores of pelitic rocks and in the supercapillary pores of reservoir rocks. The petroleum which we know as a comparatively homogeneous mass saturating highly permeable, porous, and fractured rocks is in general similar to the bituminous substances dispersed in pelitic rocks; but, at the same time, is distinguished from them by a number of specific features. Apparently the existence of petroleum with a definite bulk composition of hydrocarbon compounds is possible only in rocks permitting free migration and differentiation of fluids. All previous attempts to outline the chemical transformation of organic substances into petroleum did not take into consideration the fact that, as hydrocarbon compounds dispersed in the subcapillary pores of clay sediments migrate into highly permeable porous rocks, not only a quantitative but a qualitative change is taking place in the material. This is a physicochemical process, and a number of extensive laboratory experiments are required to understand it.

There is notable difference of opinion on the process of migration of bituminous substances jointly with water through natural reservoirs. Scale and mechanics of this phenomenon are open to discussion. It is not clear under what physical conditions the hydrocarbon compounds migrate jointly with water towards the traps in which the oil and gas pools form.

Also widely discussed are the physicochemical transformations of the oils resulting

from temperature and pressure changes in the course of the geologic history of the area to which the oil and gas accumulations are related.

In the light of these views that oil and gas accumulation zones are parts of large downwarped areas of the earth's crust, we are confronted with the question as to whether presently known oil and gas accumulations are of the same age as the traps that contain them. In this connection, it is extremely important to ascertain the age of formation of oils and gases constituting the pools.

Notwithstanding the fact that many problems still remain unsolved, the general outline presented here makes it possible to formulate the fundamental conditions for oil and gas accumulation in the earth's crust, to determine the better methods of exploration and to estimate the comparative oil and gas possibilities of large territories.

The fundamental condition is a long, slow subsidence of the earth's crust in the area under study, such that subsidence and burial of the sediments predominates over uplift in the course of the small and large oscillatory movements of the crust (Brod [13, 15]). Only subsidence of the sediments to considerable depth, and their burial by low[permeability material allows organic matter to be preserved in the subsurface and to dissociate to form new mobile bitumens. Subsidence preserves the newly-formed hydrocarbons from dispersion in water bodies. In all transormations only a certain part of the organic matter buried in sediments become hydrocarbon compounds which, under favorable conditions, may form oil and gas pools. Greater quantities of organic matter in the form of dispersed coaly particles are preserved in the rocks and can be observed easily by proper investigation.

Therefore, hydrocarbon compounds which form petroleum result from the balance between two opposing tendencies, with subsidence predominating over uplift in the course of small and large oscillations of the earth's crust in the area under study.

Should the source rock formations contain beds and lenses of sand or other highly permeable strata, migration of mobile substances from pelitic rocks into highly permeable reservoir rocks goes on during subsidence of the whole sedimentary series. Reservoir rocks under the load of overlying strata are compacted to a lesser degree than are the pelitic rocks. Mobile bituminous substances migrating from the subcapillary pore into the subcapillary pores and fissures of reservoir rocks apparently become dissolved in water and migrate together with it. During this migration, differentiation of mobile substances inside the natural reserovirs takes place.

In natural reservoirs surrounded on all sides by pelitic rocks, hydrocarbon compounds gradually fill a trap and may form an oil or gas pool enclosed on all sides. In the case of reservoir beds on a broad homocline, the hydrocarbon compounds escaping from the water accumulated in various structural folds, in wedge-out zones, in zones of unconformable overlap, and in all other areas of the reservoir rock which may serve as traps.

With subsidence predominating over uplift, the oil and gas pools are preserved in the subsurface. This process is favorable as long as the pools are not subjected to high temperatures and pressures which might destroy and disperse the oil.

Therefore, the predominance of subsidence over uplift in the course of small and large oscillations of the upper parts of the earth's crust is a fundamental condition of oil and gas formation and accumulation.

This condition, which may be considered a fundamental principle of oil and gas accumulation in the earth's crust, should serve as a chief criterion for the estimation of oil and gas possibilities of large territories.

REFERENCES

1. Aleksin, A. G., TIPY SKOPLENY NEFTI I GAZA VOSTOCHNOGO PREDKAVKAZYA [TYPES OF OIL AND GAS ACCUMULATIONS OF THE EASTERN CAUCASUS]: Nov. neft. Tekhn. Geologiya, no. 2, 1956.

2. Andrusov, N. I., K VOPROSU O PROISKHOZHDENII I ZALEGANII NEFTI [ON THE ORIGIN AND OCCURRENCE OF PETROLEUM]: Trudy Bakinskogo Otdelenia IRTO, v. 21, no. 5, 1906.

3. Andreyev, P. F., Ivantsova, V. V., Polyakova, I. N., and Silina, I. P., SVOYSTVA I STROYENIYE RASSEYANNOGO ORGANICHESKOGO VESHCHESTVA OSADOCHNYKH POROD [PROPERTIES AND STRUCTURE OF DISPERSED ORGANIC MATTER OF SEDIMENTARY ROCKS]: Geologichesky Sbornik, no. 1, Gostoptekhisdat, 1955.

4. Arkhangelsky, A. D., USLOVIYA OBRAZOVANIYA NEFTI NA SEVERNOM KAVKAZE [CONDITIONS OF OIL FORMATION IN THE NORTHERN CAUCASUS]: Izd. Sovetskoy Neft. Prom., Moscow-Leningrad, 1927.

5. Baba-Zadę, B. K., NOVIYE GEOLOGICHESSKIYE DANNYYE I ZADACHI RAZVEDOCHNYKH RABOT NA NEFTI I GAZ V AZERBAYDZHANSKOY SSR [NEW GEOLOGICAL DATA AND TASKS OF PROSPECTING WORK FOR OIL AND GAS IN AZERBAIDJAN SSR.]: Neft. Khoz., no. 12, 1956.

6. Bakirov, A. A., POL KRUPNYKH STRUKTURNYKH ELEMENTOV FUNDAMENTA RUSSKOY PLATFORMY V PROTSESSE FORMIROVANIYA REGIONALNYKH ZON

NEFTEGAZONAKOPLENIYA. In: OPYT IZUCHENIYA GEOLOGII KRISTALLI CHESKOGO FUNDAMENTA RUSSKOY PLATFORMY NA OSNOVE OPORNOGO BURENIYA [THE ROLE OF LARGE STRUCTURAL ELEMENTS OF THE BASEMENT OF THE RUSSIAN PLATFORM IN THE PROCESS OF FORMATION OF REGIONAL OIL AND GAS ACCUMULATION ZONES]: Gostoptekhisdat, 1954.

7. Bakirov, A. A., SOVREMENNOYE SOSTOYANIYE I BLIZHAYSHIYE ZADACHI ISSLEDOVANY PROTSESSOV MIGRATSII NEFTI V ZEMNOY KORE [PROCESSES OF OIL MIGRATION IN THE EARTH'S CRUST: PRESENT STATUS OF RESEARCH WORK AND FUTURE TASKS]: Sovetskaya Geologiya, Sborn. 47, 1955.

8. ___________, GEOTEKTONICHESKIYE PREDPOSYLKI DLYA POISKOV NOVYKH KRUPNYKH NEFTEGAZONOSNYKH OBLASTEY NA TERRITORII SREDNE-AZIATSKIKH RESPUBLIK [GEOTECTONIC GROUNDS FOR EXPLORATION OF NEW LARGE PRODUCTIVE AREAS ON THE TERRITORY OF MIDDLE-ASIAN REPUBLICS]: Sovetskaya Geologiya, Sborn. 57, 1957.

9. Bogdanovich, K. I., OCHERK MESTOROZHDENIYA NEFTI I DRUGIKH BITUMOV [A SHORT DESCRIPTION OF OIL FIELDS AND OTHER BITUMENS]: Kurs leksy VSNKH RIO, ser. redakstii "N" and "SKh", Part I, 1921.

10. Brod, I. O., K VOPROSAM GEOLOGICHESKOY TERMINOLOGII V SVYAZI C KLASSIFIKATSIYEY NEFTYANTKH I GAZOVYKH ZALEZHEY [GEOLOGICAL TERMINOLOGY IN CLASSIFICATION OF OIL AND GAS ACCUMULATIONS]: Sovetskaya Geologiya, Sbornik no. 9, 1946.

11. __________, O PRINTSIPAKH RAYONIROVANIYA NEFTEGAZONOSNYKH TERRITORY [PRINCIPLES OF DISTRICT DIVISION OF PRODUCTIVE AREAS]: Dokl. Akad. NaukSSSR, v. 52, no. 5, 1946.

12. ______________, MIGRATSII UGLEVODORODNYKH FLYUIDOV V ZEMNOY KORE [ON THE MIGRATION OF HYDROCARBON FLUIDS IN THE EARTH'S CRUST]: Izvestiya Akad. Nauk SSSR, Ser. geologicheskaya, no. 4, 1947.

13. ______________, OB OSNOVNOM USLOVII NEFTEGAZONAKOPLENIYA [ON THE BASIC CONDITIONS OF OIL AND GAS ACCUMULATION]: Dokl. Akad. Nauk SSSR, v. 57, no. 6, 1947.

14. ______________, OSNOVNIYE ZONY BOZMOZHNOGO NEFTEGAZONAKOPLENIYA V EVROPEYSKOY CHASTI SSSR [MAIN ZONES OF POSSIBLE OIL AND GAS ACCUMULATION IN THE EUROPEAN PART OF THE USSR]: (DOKLAD V YANVARE 1946 G. NA NAUCHNOY KONFERENTSII SARAT. GOS. UN-TA), Izd. SGU, Saratov, 1948.

15. Brod, I. O., ZALEZHI NEFTI I GAZA [OIL AND GAS POOLS]: Gostoptekhizdat, 1951.

16. _________, GEOLOGICHESKIYE PREDPOSYLKI OPENKI PERSPEKTIV NEFTEGAZONOSNOSTI. SPUTNIK POLEVOGO GEOLOGA-NEFTYANIKA [GEOLOGICAL PREREQUISITES FOR ESTIMATION OF OIL AND GAS POSSIBLITIES]: Gostoptekhizdat, Izd. I, 1952; izd. 2, v. 2, 1954.

17. __________,NEFTEGAZONOSNIYE BASSEYNY I ZONY NEFTEGAZONAKOPLENIYA, GL. X IZ KN. BRODA I EREMENKO -- OSNOVY GEOLOGII NEFTI I GAZA [OIL AND GAS BASINS AND OIL AND GAS ACCUMULATION ZONES]: Izd. MGU (Moscow State University), 1953.

18. Brod, I. O., and Mekhtiyev, Sh. F. PUTI RAZRESHENIYA PROBLEMY PROISKHOZHDENIYA NEFTI [SOME WAYS TOWARDS THE SOLUTION OF THE PROBLEM OF ORIGIN OF PETROLEUM]: Izvestiya Akad. Nauk Azerb. SSR, no. 12, 1953.

19. Brod, I. O., TEORETICHESKIYE PREDPOSYLKI POISKOV NOVYKH NEFTEGAZONOSNYKH OBLASTEY V SSSR (DOKLAD NA YUBILEYNOY SESSII MGU) [THEORECTICAL GROUNDS FOR EXPLORATION OF NEW PRODUCTIVE AREAS IN THE U. S. S. R]: Sovetskaya Geologiya, Sbornik 47, 1955.

20. Brod, I. O., and Levinson, V. G., PROISKHOZHDENIYE NEFTI I NEFTEGAZONAKOPLENIYE [ORIGIN OF PETROLEUM AND OIL AND GAS ACCUMULATION]: Gostoptekhizdat, 1955.

21. Brod, I. O., and Eremenko, N. A., OSNOVY GEOLOGII NEFTI I GAZA [PRINCIPLES OF OIL AND GAS GEOLOGY] Gostoptekhizdat, 1957.

22. Brod, I. O., GL. III. "DIAGNOSTIKA NEFTEMATERINSKIKH OTLOZHENY." GL. VII. "OTSENKA PERSPEKTIV NEFTEGAZONOSNOSTI KRUPNYKH TERRITORY". IZ. KN. I. O. BRODA I E. F. FROLOVA POISKI I RAZVEDKA NEFTYANYKH I GAZOVYKH MESTOROZHDENY [SOURCE-ROCKS. ESTIMATION OF OIL AND GAS POSSIBILITIES OF LARGE TERRITORIES. CHAPTERS

III and VII in: "EXPLORATION AND PROSPECTING OF OIL AND GAS FIELDS" By I. O. Brod and E. F. Frolov]: Gostoptekhizdat, 1957.

23. Brod, I. O., Tsaturov, A. I., and Nesmeyanov, D. V., PERSPEKTIVY NEFTEGASONOSNOSTI KARBONATYKH OTLOZHENY MEZOZOYA VOSTOCHNOGO PREDKOVKAZYA [OIL AND GAS POSSIBILITIES OF MESOZOIC CARBONATE SEDIMENTS OF THE EASTERN CAUCASUS]: Geologiya Nefti, no. 3, 1957.

24. Brod, I. O., PRINTSIPY KLASSIFIKATSII SKOPLENY NEFTI I GAZA (ZALECHI, MESTOROZHDENIYA I ZONY NEFTEGAZONAKOPLENIYA) DOKLADNA XX SESSII MEZHD. GEOL. KONGR., MEKSIKA, SENTYABR 1956. [PRINCIPLES OF CLASSIFICATION OF OIL AND GAS ACCUMULATIONS (OIL POOLS, OIL FIELD, OIL AND GAS ACCUMULATION ZONES) REPORT OF THE XX SESSION OF THE INTERN. GEOL. CONGRESS, MEXICO, SEPTEMBER 1956]: Materialy po geologii Nefti, v. 1, Gostoptekhizdat, Moscow, 1958.

25. Vassoyevich, N. B., and Uspensky, V. A., GEOLOGIYA NEFTI GL IZ KN. SPUTNIK POLEVOGO GEOLOGA-NEFTYANIKA [OIL GEOLOGY in "SPUTNIK POLEVOGO GEOLOGA-NEFTIANIKA"]: v. 1, Izd. Vtoroye, 1954.

26. Vassoyevich, N. B., O PROISKHOZHDENII NEFTI [ON THE ORIGIN OF PETROLEUM.] Materialy K XX Sessii Mejdunar. Geol. Congr., v. 1, Gostoptekhizdat, 1957.

27. Veber, V. V., VOPROSY NEFTEOBRAZOVANIYA PO DANNYM IZUCHENIYA SOVREMENNYKH MORSKIKH OSADKOV, SBORNIK [PROBLEMS OF OIL FORMATION ACCORDING TO DATA GATHERED FROM THE STUDY OF RECENT MARINE SEDIMENTS]: Sbornik. Materialy discussii po problems proiskhojdeniia i migrastiia i migrastii nefti: Izd. Akad. Nauk Ukr. SSR, Kiev, 1955.

28. Veber, V. V., PROBLEMA BITUMOOBRAZOVANIYA V CHETVERTICHNYKH MORSKIKH OSADKAKH I GENEZIS NEFTI. [PROBLEM OF BITUMEN FORMATION IN QUARTERNARY MARINE SEDIMENTS AND GENESIS OF PETROLEUM]: Mater. k XX sessii Mejd. Geol. Cong. Materialy po geologii Nefti, v. I, Gostoptekhizdat, 1957.

29. GEOLOGICHESKY SBORNIK No. 1, (VOPROSY PROISKHOZHDENIYA NEFTI). [PROBLEM OF ORIGIN OF PETROLEUM] Trudy VNIGRI, nov. ser., no. 83, Gostoptekhizdat, 1955.

30. GEOLOGICHESKY SBORNIK no. 2, Trudy VNIGRI, nov. ser., no. 95, Gostoptekhizdat, 1956.

31. Gorin, V. A., ROL TEKTONICHESKIKH NARUSHENY PRI RASPREDELENII NEFTI V OTLOZHENIYAKH APSHERONSKOGO POLUOSTROVA [THE ROLE OF TECTONIC FAULTS IN DISTRIBUTION OF PETROLEUM IN THE SEDIMENTS OF THE ASPHERON PENINSULA]: Azerb. Neft. Khoz., no. 8, 1940.

32. __________, O NEKOTORYKH ZAKONOMERNOSTYAKH V RASPREDELENII NEFTI V PODKIRMAKINSKOY SVITE PRI BOKOVOY MIGRATSII [ON SOME REGULARITIES IN OIL OCCURRENCE IN PODKIRMAKINSKOY FORMATION AT LATERAL MIGRATION]: Azerb. Neft. Khoz., no. 2-3, 1946.

33. Gubkin, I. M., MAYKOPSKY NEFTENOSNYY RAYON. NEFTYANO-SHIRVANSKAYA NEFTENOSNAYA PLOSHCHAD [MAYKOP PETROLIFEROUS PROVINCE NEFTE-SHIRVAN PRODUCTIVE AREA]: Trudy Geolog. Kom., nov. ser., no. 78, Izd. Geologichesky Komitet, 1912.

34. __________, UCHENIYE O NEFTI. [SCIENCE OF PETROLEUM]: Izd. I, 1932; Izd. 2, 1937.

35. __________, TEKTONIKA YUGO-VOSTOCHNOY CHASTI KAVKAZA V SVYAZI S NEFTENOSNOSTYU ETOY OBLASTI [TECTONICS OF THE SOUTH-EASTERN PART OF THE CAUCASUS IN CONNECTION WITH OIL POSSIBILITIES OF THIS REGION]:ONTI, 1934.

36. __________, K VOPROSU O GENEZISE NEFTYANYKH MESTOROZHDENY SEVERNOGO KAVKAZA. [ON THE ORIGIN OF THE NORTH-CAUCASIAN OIL FIELDS.] Trudy Mejdunar. Geol. Cong. 1937, v. 4, Moscow, 1940.

37. __________, URALO-VOLZHSKAGA NEFTENOSNAYA OBLAST (VTOROYE BAKU) [URAL-VOLGA PRODUCTIVE AREA (SECOND BAKU)]: Moscow, Akad. Nauk SSSR, 1940.

38. Dvali, M. F., and Drobyshev, D. V. KRITERII PROGNOZA NEFTENOSNOSTI V PRAKTIKE POISKOVYKH RABOT V SSSR. [CRITERIA OF PROGNOSIS OF OIL POSSIBILITIES IN THE PRACTICE OF EXPLORATION WORK IN THE U. S. S. R.]: Materialy k XX Session

Mejd. Geol. Cong., Mater. po. geologii nefti]: v. 1, Gostoptekhizdat, 1957.

39. Eremenko, N. A., Maksimov, S. P., and Tkhostov, B. A., O TSIKLAKH BITUMOOBRAZOVANIYA NA SEVERO-VOSTOCHNOM KAVKAZE [ON THE CYCLES OF BITUMEN FORMATION IN THE NORTH-EASTERN CAUCASUS]: Neft. Khoz., no. 12, 1949.

40. Ignatovich, N. K., O REGIONALNYKH GIDROGEOLOGICHESKIKH ZAKONOMERNOSTYAKH V SVYAZI S OTSENKOY USLOVY NEFTENOSTI [ON THE REGIONAL HYDROGEOLOGICAL REGULARITIES IN CONNECTION WITH ESTIMATION OF OIL POSSIBILITIES]: Sovetskaya Geologiya, no. 6, 1944.

41. Konyukhov, I. A., BITUMINOLOGICHESKIYE OSOBENNOSTI MEZOZOYSKIKH OTLOZHENY VOSTOCHNOY CHASTI SEVERNOGO SKLONA KOVKAZA [BITUMINOLOGICAL FEATURES OF MESOZOIC SEDIMENTS OF THE EASTERN PART OF THE NORTHERN SLOPE OF THE CAUCASUS]: Nov. Neft. Tekhn., Geologiya, no. 1, 1956.

42. ____________, NEFTENOSNOST MEZOZOYSKIKH OTLOZHENY SEVERNOGO KAVKAZA [OIL POSSIBILITIES OF MESOZOIC SEDIMENTS OF THE NORTHERN CAUCASUS]: Nov. Neft. Tekhn. Dopolnit. Sbornik, Geologiya, 1956.

43. Krems, A. Ya., VOPROSY FORMIROVANIYA ZALEZHEY NEFTI I GAZA [PROBLEM OF FORMATION OF OIL AND GAS POOLS]: Gostoptekhizdat, 1954.

44. Kudryavtsev, N. A., SOVREMENNOYE SOSTOYANIYE PROBLEMY PROISKHOZHDENIYA NEFTI. IZ KN. [PRESENT STATUS OF THE PROBLEM OF PETROLEUM ORIGIN] in "Materialy discussii po problems proiskhojdenya i migrastii nefti": Izd. Akad. Nauk Nauk Ukr. SSR, Kiev, 1955.

45. Linetsky, V. F., GEOLOGO-FIZICHESKIYE OSNOY MIGRATSII NEFTI. [GEOLOGICAL AND PHYSICAL BASE OF OIL MIGRATION. D. Sc. dissertation]: Lvov, 1956.

46. Lindtrop, N. T., ROL VODY V FORMIROVANII I RAZRUSHENII NEFTYANYKH ZALEZHEY [THE ROLE OF WATER IN THE FORMATION AND DESTRUCTION OF OIL POOLS]: Sbornik pamyati academika I. M. Gubkina, Akad. Nauk SSSR, 1951.

47. Maymin, Z. L., KUSLOVIYAM OBRAZOVANIYA NEFTI V PALEOZOYSKIKH OTLOZHENIYAKH VOSTOCHNOY CHASTI RUSSKOY PLATFORMY. [CONDITIONS OF OIL FORMATION IN PALEOZOIC SEDIMENTS OF THE EASTERN PART OF THE RUSSIAN PLATFORM]: Mater. k XX Sess. Mejd. Geol. Cong. v. 1, Gostoptekhizdat. 1957.

48. Maksimov, S. P., K VOPROSU FORMIROVANIYA PERMSKIKH ZALEZHEY NEFTI URALO-VOLZHSKOY NEFTEGAZONOSNOY OBLASTI [PROBLEMS OF FORMATION OF PERMIAN OIL BEDS OF THE URAL-VOLGA PRODUCTIVE REGION]: Neft. Khoz. no. 10, 1955.

49. ____________, USLOVIYA FORMIROVANIYA ZALEZHEY NEFTI V MESTOROZHDENII YABLONOVYY OBRAG [CONDITIONS OF FORMATION OF OIL POOLS IN YABLON OVYYOVRAG]: Trudy akademii Neftianoi prom., no. 2, Gostoptekhizdat, 1955.

50. Mekhtiyev, Sh. F., and Bayramova, A. S. PERIODICHNOST V NEFTEOBRAZOBANIYA I VERTIKALNOYE RASPREDELENIYE ZALEZHAKH NEFTI [CYCLES OF OIL FORMATION AND VERTICAL DISTRIBUTION OF OIL POOLS]: Doklady Akad. Nauk Azerb. SSR, v. 4, no. 12, 1948.

51. ________________, O VISYACHIKH ZALEZHAKH NEFTI V NIZHNEM OTDELE PRODUKTIVNOY TOLSHCHI APSHERONSKOGO POLUOSTROVA [ON HANGING OIL POOLS IN THE LOWER SECTION OF THE PRODUCTIVE SERIES OF APSHERON PENINSULA]: Izd. Akad. Nauk SSR, no. 7, 1949.

52. Mekhtiyev, Sh. F., O PROISKHOZHDENII NEFTI I FORMIROVANII YEYE ZALEZHEY V AZERBAYDZHANE [ON THE ORIGIN OF PETROLEUM AND FORMATION OF OIL POOLS IN AZERBAIDJAN]: Materialy k XX Sessii Mejd. Geol. Cong. v. 1, Gostoptekhizdat, 1957.

53. Mikhaylovsky, G. P., NESKOLKO SOOBRAZHENY O PROISKHOZHDENII KAVKAZSKOY NEFTI [SOME CONSIDERATIONS REGARDING THE ORIGIN OF CAUCASIAN OIL]: Izv. Geol. Komiteta, 25, no. 6, 1906.

54. Mirchink, M. F., STRATIGRAFICHESKIYE ZALEZHI NEFTI, BAKU [STRATIGRAPHIC TYPE OIL POOLS, BAKU]: Izd. Azerb. Filiala Akad. Nauk SSSR, 1943.

55. ____________, O PRINTSIPAKH KLASSIFIKATSII ZALEZHEY NEFTI I GAZA

[PRINCIPLES OF CLASSIFICATION OF OIL AND GAS POOLS]: Neft. Khoz. no. 6, 1955.

56. Mirchink, M. F., ZADACHI RAZVITIYA GEOLOGO-RAZVEDOCHNYKH RABOT NA NEFT I GAZ [DEVELOPMENT OF GEOLOGICAL PROSPECTING WORK FOR OIL AND GAS]: Neft. Khoz. no. 6, 1956.

57. Mirchink, M. F., and Bakirova, A. A., O GEOTEKTONICHESKOM RAZVITII RUSSKOY PLATFORMY I OSNOVNYKH ZAKONOMERNOSTYAKH RAZMESHCHENIYA ZON NEFTEGAZONAKOPLENIYA NA YEYE TERRITORII. [ON THE GEOTECTONIC DEVELOPMENT OF THE RUSSIAN PLATFORM AND PRINCIPAL REGULARITIES IN DISTRIBUTION OF OIL AND GAS ACCUMULATION ZONES ON ITS TERRITORY]: Materialy k XX Sessii Mejd. Geol. Cong. v. 1, Gostoptekhizdat, 1957.

58. Mustafinov, A. N., K VOPROSU O GEOLOGICHESKIKH USLOVĪYAKH FORMIROVANIYA ZALEZHEY NEFTI V KUYBISHEVSKOM POVOLZHYE [GEOLOGICAL CONDITIONS OF FORMATION OF OIL FIELDS IN KUIBYSHEV-VOLGA AREA]: Sovetskaya Geologiya, Sbornik 57, 1957.

59. ____________, NEFTEGAZONOSNOST VOSTOCHNOY CHASTI RUSSKOY PLATFORMY DOKLADY NA XX SESSII MEZHDUNAR. GEOL. KONGR. MATER. PO GEOLOGII NEFTI [OIL POSSIBILITIES OF THE EASTERN PART OF THE RUSSIAN PLATFORM (REPORT TO THE XX SESS. OF THE INT. GEOL. CONG. MEXICO, 19560]: Materialy po geologii nefti, v. 1, Gostoptekhizdat, 1957.

60. Mirchink, M. F., Bakirov, A. A., Dyakov, B. F., and Zhabrev, D. V., editors, PROISKHOZHDENIYE NEFTI (SYMPOSIUM ON ORIGIN OF PETROLEUM]: Moscow, 1955.

61. Porfiryev, V. B., and Linetsky, V. F., VOPROSY MIGRATSII NEFTI [PROBLEM OF OIL MIGRATION]: Trudy Lvovskogo Geol. Obshchestva pri gos. Geol. Universitete im. Franko, ser. geologicheskaia, no. 2, Izd. Kharkovskogo Gos. Universiteta, 1952.

62. Porfiryev, V. B., PUTI I FAKTORY OBRAZOVANIYA NEFTI. SBORNIK MATERIALY DISKUSSII PO PROBLEME PROISKHOZHDENIYA I MIGRATSII NEFTI [WAYS AND FACTORS DETERMINING OIL FORMATION]: Materialy Discussii po Probleme Proiskhojdeniia i Migrastii Nefti. Izd. Akad. Nauk Ukr. SSR, Kiev, 1955.

63. Snarsky, A. N., PUTI MIGRATSII NEFTI I GAZA [WAYS OF OIL AND GAS MIGRATION]: Nauch. Zapiski Lvovskogo Politekhnicheskogo Instituta, no. 28, ser. neftianaia, no. 5, 1955.

64. Sokolov, V. A., MIGRATSIYA GAZA I NEFTI [OIL AND GAS MIGRATION]: Izd. Akad.Nauk SSR, 1956.

65. Strakhov, N. M., and Rodionova, K. F., O SVYAZO RASSEYANNYKH BITUMOV S PETROGRAFICHESKIMI TIPAMI OSADOCHNUKH POROD [ON THE RELATION BETWEEN DISPERSED BITUMENS AND PETROGRAPHIC TYPES OF SEDIMENTARY ROCKS]: Byull. MOIP (Moscow Society of Naturalists), otd. geologii, v. 29, no. 2, 1954.

66. Sukharev, G. M., GIDROGEOLOGIYA MEZOZOYSKIKH I TRETICHNYKH OTLOZHENY TERSKO-DAGESTANSKOY NEFTEGAZONOSNOY OBLASTI I NIZHNEGO POVOLZHYA [HYDROGEOLOGY OF MESOZOIC AND TERTIARY DEPOSITS OF TERSKO-DAGHESTAN AND LOWER VOLGA PETROLIFEROUS REGIONS]: Gostoptekhizdat, 1954.

67. Teodorovich, G. I., O GEOKHIMICHESKIKH I DRUGIKH USLOVIYAKH, BLAGOPRIYATSTVUYUSHCHIKH DLYA OBRAZOVANIYA NEFTYANYKH BITUMOV [ON THE GEOCHEMICAL AND OTHER FACTORS FAVORABLE FOR FORMATION OF PETROLEUM BITUMENS]: Nefti. Khoz., no. 12, 1952.

68. ____________, O NEFTEPROIZVODYASHCHIKH PORODAKH [ON THE SOURCE ROCKS]: Neft. Khoz. no. 8, 1954.

69. Trofimuk, A. A., USLOVIYA OBRAZOVANIYA NEFTYANYKH MESTOROZHDENY URALOVOLZHSKOY NEFTENOSNOY [CONDITIONS OF FORMATION OF OIL AND GAS FIELDS OF THE URAL-VOLGA PRODUCTIVE REGION]: Izd. Akad. Nauk SSSR, 1955.

70. Ulyanov, A. V., USLOVIYA FORMIROVANIYA NEFTYANYKH I GAZOVYKH MESTOROZHDENY ZAPADNOGO KAVKAZA [CONDITIONS OF FORMATION OF OIL AND GAS FIELDS OF THE WESTERN CAUCASUS]: Sbornik Pamyati acad. I. M. Gubkina, Akad. Nauk SSSR, 1951.

71. Uspenskaya, N. Yu., O PRINTSIPAKH KLASSIFIKATSII NEFTEGAZONOSNYKH PROVINTSY [PRINCIPLES OF CLASSIFICATION OF OIL AND GAS PROVINCES]: Trudy MNI, no. 5, 1947.

72. Uspenskaya, N. Yu., NEKOTORYYE KAKONOMERNOSTI NEFTEGAZONAKOPLENIYA NA PLATFORMAKH [SOME REGULARITIES OF OIL AND GAS ACCUMULATION ON PLATFORM TERRITORIES]: Gostoptekhizdat, 1952.

73. Uspensky, V. A., K VOPROSU GENEZISA TIPOV NEFTEY [PROBLEM OF GENESIS OF VARIOUS TYPES OF PETRO LEUM]: Gostopthekhizdat, 1947.

74. Yurkevich, I. Yu., O NEFTEMATERINSKIKHPORODAKH [ON THE SOURCE ROCKS]: Sovetskaya Geologiya, Sbornik 47, 1955.

75. Khain, V. E., GEOTEKTONICHESKIYE OSNOVY POISKOV NEFTI [GEOTECTONIC PRINCIPLES IN PROSPECTING FOR OIL]: Aznefteizdat, Baku, 1954.

76. Khelkvist, G. A., ZONALNYYE NEFTYANIYE ZALEZHI I METODY IKH RAZVEDKI [ZONAL OIL ACCUMULATIONS AND METHODS OF THEIR PROSPECTING]: Gostopthekizdat, 1954.

77. Beeby-Thompson, A., OIL-FIELD EXPLORATION AND DEVELOPMENT: 2nd. ed., London, 1950.

78. Bloesch, E., Bartram, J. G., Hoots, H. W., Lahee, F. H., Millikan, C. V., Umpleby, J. B., and Wilson, W. B., CLASSIFICATION OF VARIOUS FORMS OF OIL MIGRATION: Bull. AAPG, v.5, 1936.

79. Blumer, Ernst, DIE ERDÖLLAGERSTÄTTEN AND ÜBRIGEN KOHLENWASSERSTOFFVORKOMMEN DER ERDRINDE GRUNDLAGEN DER PETROLEUM-GEOLOGIE; Stuttgart, 1922.

80. Brod, I. O., GEOLOGICAL TERMINOLOGY IN CLASSIFICATION OF OIL AND GAS ACCUMULATIONS: Bull. AAPG, v. 29, no. 12, 1945.

81. Campbell, M. R., HISTORICAL REVIEW OF THEORIES ADVANCED BY AMERICAN GEOLOGISTS TO ACCOUNT FOR THE ORIGIN AND ACCUMULATION OF OIL: Econ. Geology, v. 6, no. 4, June, 1911.

82. De Cizancourt, CARACTÈRES GÉNÉRAUX DES GISEMENTS PÉTROLIFÈRES: Annales de l'Office National des Combustibles Liquides, v. 11, no. 6, 1936.

83. Clapp, F. G., A PROPOSED CLASSIFICATION OF PETROLEUM AND NATURAL GAS FIELDS: Econ. Geol., v. 5, 1910.

84. Clapp, F. G., ROLE OF GEOLOGIC STRUCTURE IN THE ACCUMULATION OF PETROLEUM. STRUCTURE OF TYPICAL AMERICAN OIL FIELDS: Pan. Am. Geol., 1930.

85. DISCUSSION, DIFFERENTIAL ENTRAPMENT OR OIL AND GAS: Bull. AAPG. no. 2, 1955.

86. Emmons, W. H., GEOLOGY OF PETROLEUM: New York and London, 1931.

87. Fash, R. H., THEORY OF ORIGIN AND ACCUMULATION OF PETROLEUM: Bull. AAPG. no. 10, 1944.

88. Gussow, W. G., DIFFERENTIAL ENTRAPMENT OF OIL AND GAS, A FUNDAMENTAL PRINCIPLE: Bull. AAPG, no. 5, 1954.

89. ________, TIME OF MIGRATION OF OIL AND GAS: Bull. AAPG, v. 39, no. 5, 1955.

90. ________, IN SITU ORIGIN OF MCMURRAY OIL OF NORTHWESTERN ALBERTA AND ITS REFERENCE TO GENERAL PROBLEM OF ORIGIN OF OIL: DISCUSSION, Bull. AAPG, no. 8, 1955.

91. Hobson, G. D., FAULTING AND OIL ACCUMULATION: J. Inst. Petrol., I. v. 42, 1945.

92. Höfer, H., DAS ERDÖL UND SEINE VERWANDTEN: Leoben, 1888.

93. Howard, W. V., NORTHERN HEMISPHERE OFFERS GREATER OIL POSSIBILITIES: Oil and Gas Journal, v. 39, no. 35, 1941.

94. Illing, V. C., SOME FACTORS IN OIL ACCUMULATION: J. Inst. Petroleum, IV, v. 25, no. 186, 1939.

95. ________, GEOLOGY APPLIED TO PETROLEUM. PART I. - PETROLEUM IN THE SEDIMENTARY CYCLE: The Oil Weekly, v. 122, no. 7, 1946.

96. Illing, V. C. (Editor), THE WORLD'S OIL FIELDS. THE EASTERN HEMISPHERE: The Science of Petroleum, v. 6, part I, 1953.

97. Kaufman, C. F., THE TECTONIC FRAMEWORK OF THE FAR EAST AND ITS INFLUENCE ON THE ORIGIN AND ACCUMULATION OF PETROLEUM: Third World Petroleum Congress, The Hague. Leiden, 1951.

98. Krejci Graf, Karl, GRUNDFRAGEN DER

ÖLGEOLOGIE: Stuttgart, 1930.

99. Lahee, F. H., A STUDY OF THE EVIDENCE FOR LATERAL AND VERTICAL MIGRATION OF OIL: Problems of Petroleum Geology, 1934.

100. Lalicker, C. G., PRINCIPLES OF PETROLEUM GEOLOGY: New York, 1949.

101. Landes, K. K., PETROLEUM GEOLOGY: New York, 1951.

102. De Launay, TRAITÉ DE MÉTALLOGÉNIE, GITES MINÉRAUX ET MÉTALLIFÈRES: Paris, 1913.

103. Levorsen, A. J., STRATIGRAPHIC VERSUS STRUCTURAL ACCUMULATION. Bull. AAPG, v. 20, no. 5, 1936; Oil and Gas Journal, v. 34, no. 45, 1936.

104. ____________, GEOLOGY OF PETROLEUM: San Francisco, 1954.

105. Lilley, E. R., THE GEOLOGY OF PETROLEUM AND NATURAL GAS: New York, 1928.

106. Macovei, Georges, LES GISEMENTS DE PÉTROLE: Paris, 1938.

107. Pratt, W. E., OIL IN THE EARTH: Lawrence, Kansas, 1944.

108. __________, PETROLEUM ON CONTINENTAL SHELVES: Bull. AAPG, no. 4, 1947.

109. Russel, W. L., PRINCIPLES OF PETROLEUM GEOLOGY: New York, Toronto, London, 1951.

110. Schuchert, C. H., PETROLIFEROUS PROVINCES: Bull. Am. Inst. Min. Met., no. 155, 1919.

111. Smith, P. V., STUDIES ON ORIGIN OF PETROLEUM; OCCURRENCE OF HYDROCARBONS IN RECENT SEDIMENTS: Bull. AAPG, v. 38, no. 3, 1954.

112. __________, STATUS OF OUR PRESENT INFORMATION ON THE ORIGIN AND ACCUMULATION OF OIL: Fourth World Petroleum Congress. Proceedings, section 1, Rome, 1955.

113. Stutzer, O., ERDÖL. ALLGEMEINE ERDÖLGEOLOGIE UND ÜBERBLICK ÜBER DIE GEOLOGIE DER ERDÖLFELDER EUROPAS: Berlin, Verlag von Gebrüder Bointraeger, 1931.

114. Tiratsoo, E. N., PETROLEUM GEOLOGY: London, 1951.

115. Trask, P. D., and Patnode, H. W., SOURCE BEDS OF PETROLEUM: 1942.

116. Van Tuyl, F. M., Parker, B. H., and Skiters, W. W., THE MIGRATION AND ACCUMULATION OF PETROLEUM AND NATURAL GAS: Quarterly of the Colorado School of Mines, v. 40, no. 1, 1945.

117. Ver Wiebe, W. A., OIL FIELDS OF THE UNITED STATES: 1930.

118. Wilcox, J., SOURCE BEDS OF PETROLEUM AND SEARCH FOR OIL: World Petroleum, no. 4, 1945.

119. Woodruff, E., PETROLIFEROUS PROVINCES: Bull. Am. Inst. Min. Met. Ing., no. 150, 1917.

GEOLOGY OF THE ANGARA REGION[1]

by

M. M. Odintsov[2]

• *translated by Cyril Muromcew* •

ABSTRACT

Industrial development of the Angara region has necessitated geological exploration for available resources. The Angara River flows north from Lake Baikal, intersecting the mountains surrounding it; passes through the 'Irkutsk Amphitheater,' part of the central Siberian platform; and, near Bratsk, flows across a diabase intrusion, forming the Bratsk rapids (approximately 300 kilometers long). The Angara river basin is underlain by crystalline basement (the Siberian craton) composed of schists, gneisses, marble, and Archean and Proterozoic granites. These rocks dip sharply from the Sayan and Baikal ranges, where they outcrop, toward the Irkutsk Amphitheater, where they reach 3000 meters depth. The craton is covered by sediments ranging in age from Cambrian to Quaternary. Lower Cambrian rocks over 2500 meters thick are overlain by Middle Cambrian strata which are generally eroded. In the Irkutsk coal basin, north of Lake Baikal, Mesozoic rocks 600 meters thick are covered unconformably by Tertiary sediments. Quaternary deposits are known to occur; the Angara River terraces are probably pre-Quaternary. Regional tectonics involved fracturing within the Irkutsk Amphitheature and in the surrounding mountains. Geophysical survey and drilling revealed a wide horizontal protrusion (the 'Angara swell') in the Siberian craton; this protrusion divides the Irkutsk Amphitheater in the Pre-Baikal and Pre-Sayan depressions. Overlying Cambrian sediments are folded in conformity with these basement-complex dislocations. Jurassic deposits, generally horizontal, are disturbed only near the younger uplifts of Sayan and Baikal. The southwestern part of a large trap-rock intrusion crosses the Irkutsk Amphitheater; concordant intrusions, e. g. sills, entered lower Paleozoic sediments along with dikes, during late Permian and, principally, Triassic times. Mineral deposits are rich and varied: Precambrian rocks contain magnetic iron ore (of the Krivoy Rog type); talc; magnesite; pure crystalline limestone; and, possibly, phosphates. Paleozoic rocks contain large marine and lacustrine salt deposits, gypsum, phosphatized shell rock, and, possibly, oil: as well as carbonaceous rocks with lead and zinc minerals. Hydrogen-sulfide -saturated and saline mineral waters as well as subsurface water with high potassium content occur in Cambrian rocks. Siberian trap rocks are rich in magnesium and iron; magnesium-magnetite ores occur in volcanic necks as large veins of pure ore, associated with tuffs and aureoles. Trap rock (diabase) may be used in the new stone-melting industry. Jurassic deposits include saprolitic-bog and humus coals as well as extensive fire-clay and high-quality kaolin deposits. Cambrian fossils include trilobite and brachiopod remains, reefs, and molluscs; fish, insects, ostracods, and numerous fossil plant traces, are representative of the Mesozoic. The Angara River terraces, 25 to 30 meters thick, contain mammal remains, brackish-water molluscs, and, from the Middle Paleolithic, Azilian and Solutrean artifacts. -- D. D. Fisher

The economic development of East Siberia resulting from construction of a number of hydroelectric power stations, will lead to large scale exploration for mineral resources needed by the various brances of the industry in this area. It will be necessary to look for local sources of building material, to study ground water conditions, and to compile engineering maps as a basis for determination of future plant sites, towns, and means of transportation.

Currently, geology of the Angara region may be described as follows: The mountains surrounding the deep and narrow Lake Baikal basin are cut on the south-west by the wide Angara River valley. Farther down, the Angara River flows through the so-called Irkutsk Amphitheater, a part of the Central Siberian plateau located among the high mountain ridges of East Sayan to the southwest and the Baikal Mountains to the southeast. Near the town of Bratsk [approximate location: 56°N, 102°E], the Angara River cuts across an area of diabase intrusions and forms the famous Bratsk rapids which continue for nearly 300 km. From the source of the Angara River [approximate location: 52°N, 105°E] to the Bratsk rapids, numerous basement rocks of varying composition and age are exposed in the Angara river basin. The oldest rocks there are among the oldest rocks of the Earth's crust, namely: crystalline schists, gneisses, marble, and Archean and Proterozoic granites. These rocks form the firm and consolidated base of the Siberian craton, found at a depth of 3000 m. and covered by sediments ranging from Lower Cambrian to Quaternary.

---

[1] Translated from Geologiya Priangarya: Priroda, no. 1, 1957, p. 87-90.

[2] U.S.S.R. Akademy of Sciences Eastern Siberian Affiliate Irkutsk.

The crystalline basement outcrops in the Sayan and Baikal mountain ranges.

Precambrian rocks on the craton contain n numerous and varied mineral deposits such as iron ore (of the Krivoy Rog type), talc, magnesite, pure crystalline limestone (raw material for chemical and cement industries, quartzites et al.). There is reason to expect the discovery of phosphates.

Precambrian rocks of the Siberian platform dip sharply from the Sayan and Baikal ranges towards the central part of the Irkutsk amphitheater; and, are covered by lower Paleozoic, in particular Cambrian and Ordovician, rocks. Their stratigraphic cross section has been studied carefully by means of deep bore holes which, in a number of cases, have penetrated sediments to the basement complex. Among Cambrian rocks there are several formations and stages of well-defined composition containing characteristic fauna. Lower Cambrian deposits are over 2500 thick. Carbonaceous deposits containing trilobite and brachiopod remnants that set their age as Middle Cambrian, have escaped erosion only in the northern part of the Irkutsk amphitheater. These are covered unconformably by red lagoonal deposits containing crustacean remnant. The so-called Verkholensk stage (Upper Cambrian) contains some economic gypsum deposits and some lean, sedimentary copper ores.

On top of the Verkholensk formation, rest conformably Ordovician strata consisting of limestones, sandstones, reefs, clayey sandstones,. phosphatic sediments, and red lagoonal deposits; altogether 600 thick, they represent various stages. Ordovician deposits are rich in brachiopods, molusks, crustaceans, and trilobites. On top of the Ordovician deposits, rest unconformably silurian quartzites up to 90 thick which belong to the Kezhem stage; these are the youngest Lower Paleozoic deposits in the area.

FIGURE 1. Angara River at its source. View down stream.

Devonian deposits are absent altogether in the Pre-Angara area; Upper Paleozoic rocks (Carboniferous and Permian) cover large areas in the central part of the Angara River course. This area lies north of the Ilim River, outside of the Irkutsk amphitheatre, and includes the Tungursk coal-bearing basin. It is probable that at one time Permian and Carboniferous deposits extended beyond the present-day borders of the Tungursk basin; this is indicated by some remnants of those rocks in the Pre-Sayan area between the rivers Uda and Birius.

In the Pre-Angara region, widespread Jurassic rocks fill the Irkutsk coal basin which extends north from the Baikal Lake as far as the rivers Uda and Biryusa, and continues along the East Sayan ridge. Jurassic deposits are represented here by lacustrine and paludal sediments such as sandstones, silt, conglomerates with saprolitic and humus coal, and refractory clay. Few bossils are found in these sediments: those that occur are mostly fish, insects, and ostracods. There are, however, numerous traces of fossil plants. Thickness of the sediments, varying considerably, ranges up to 600 m. In the southeastern part of the Irkutsk basin and in Pre-Baikal, Jurassic deposits are covered unconformably by Tertiary sediments.

FIGURE 2. Angara River above the village of of Sukhovo (view from the right bank of the river valley of the Angara and the low terraces on the left bank)

Quaternary deposits in the Pre-Angara area are varied and little is known about them. The oldest and the highest terraces of the Angara River and associated depressions, are probably of pre-Quaternary age.

In Angara terrace sediments 25-30 thick, there were found remnants of nothern elk, ox, mammoth, furry rhinoceros, cave lion, and brackish-water molluscs, as well as some

paleolithic tools belonging to the Azilian and Solutrean period. Well known are the ancient inhavitants of Malta [village, approximate location: 53°N, 103° 30'E] during Middle Paleolithic. Traces of these people have been found in a 15-18 meter thick terrace of the Angara River.

Quite noteworthy is the tectonic structure of the Pre-Angara region. The Irkutsk Amphitheater is filled with sediments and is surrounded by the steep slopes of the Baikal and East Sayan ridges. On the periphery of surrounding mountains and inside of the amphitheater, there are numerous faults and dislocations which bring into contact rocks of different ages.

Recently it was discovered by means of deep drilling and geophysical surveys (I. P. Karasev, 1955 et al.) that the old basement complex of the Siberian craton forms in the Pre-Angara area a wide horizontal protrusion; this is the so-called Angara swell which extends in northern direction from Pre-Sayan up to the central part of the Angara River. The Angara swell divides the Irkutsk amphitheatre into two parts: the Pre-Baikal and the Pre-Sayan depressions. Cambrian sediments covering these depressions and the swell, are folded, forming a linear structural element that trends northeast along the Baikal range, as well as the dome-like brachy folds with ill-defined contours in the central part of the amphitheatre and in the Sayan depression. These structures of the sedimentary cover conform to major deep-seated dislocations in the old basement complex.

Of some interest are series of long and narrow folds with a northeast strike, involving Cambrian and Ordovician sediments. These cover the northern part of the Irkutsk amphitheatre, the Ilim and Nep basins, and the Lower Tungursk highlands. These folds, closely spaced in the Nep basin, seem to spread out in the Angara-Ilim area and appear to flow around the Angara swell.

Jurassic deposits of the Irkutsk coal basin, disturbed only in the area of younger uplifts of Sayan and Baikal, have generally a horizontal attitude.

In the area of widespread basic intrusions, Siberian trap rocks form numerous intrusions along bedding planes; and, as well, form laccoliths, dikes, and sills in Lower Paleozoic sediments. The southeast border of the trap-intruded area runs across the Irkutsk amphitheatre. This area stretches from Pre-Sayan to the Bratsk area and to the central part of the Ilim River. Trap intrusions in to Lower Paleozoic rocks took place towards the end of the Permian, but mostly during the Triassic. The mechanics of intrusion of large basic-lava

FIGURE 3. Outcrop of Jurassic sandstone on the right shore of the Angara River between villages Ust-Kuda and Ust-Baley

masses, similar in composition to the plateau basalt, has not yet been explained. Apparently, the ancient basement complex of the Siberian craton underwent deep-seated faulting which later served to channel the basic magma; in tectonically weak parts, volcanic foci were formed.

Basic magma of Siberian trap rocks rich in magnesium and iron formed the large iron ore deposits in the Angara-Ilim area, in which there are huge volcanic cones filled with tuffaceous material. Magnesium-magnetite ores form large veins of pure ore in tuffs and aureoles of disseminated ore with in tuffaceous materials in the volcanic necks.

In the Pre-Angara region, there are many rich and complex mineral deposits associated with certain geologic periods. Precambrian deposits consist of metamorphosed Archean and Proterozoic magnetic ores. The northeast slopes of the sayan ridge contain iron ore, magnesium, and talc.

Lower Paleozoic lacustrine and marine sediments contain large salt deposits. The saline basin of the Irkutsk amphitheatre is the largest in the world. Gypsum is found in Upper Cambrian deposits of the Verkhoyansk stage. Ordovician deposits contain beds of phosphatized shell rock and sandstones with pockets of phosphates.

Of some interest is the possibility that oil deposits may occur in the Lower Paleozoic rocks. Lower Cambrian formations have high bitumen content and contain inclusions of asphaltites and even some oil. It is still necessary to find suitable host rocks and tectonic structures where large oil deposits may have formed.

Little is known about the possibility that ore deposits may occur in Lower Paleozoic rocks. In the 18th century, a discovery was made of some copper-bearing sandstones along the Lena River; some copper was produced there in small smelters. Cambrian and Ordovician carbonaceous rocks contain some zinc and lead minerals. There is a possibility that ore deposits in commercial quantities man be found.

Of great balneologic importance are mineral waters from some of the Cambrian rocks. In many parts of the Pre-Angara region saline waters saturated with hydrogen sulfide rise to the surface under pressure along fissures and form natural springs. These waters also rise from great depths through bore holes. In composition and in medical value they are similar to the Matsesta waters. Several spas are already in operation. In some places in the Irkutsk area, concentration of potasium was noted in subsurface waters indicating the possibility that potasium deposits may occur there. During the Upper Paleozoic and Lower Mesozoic stages of development an intrusion of Si-

FIGURE 4. Angara River above the village of Sukhovo. View of the main channel and of the high right bank consisting of Jurassic sandstone

berian trap rocks took place. Exploitation of magnetite ores in the Angara-Ilim area is scheduled for the sixth Seven-year Plan. Siberian trap rocks (diabase) also may be used in the new branch of industry called stone melting [Petrurgii]. Products made of molten diabase have good resistance to acids, good diaelectric properties, and suitable mechanical properties. These products will find wide application in the chemical and electrical industries, and allied branches.

The Jurassic stage of development, characterized by continental environment, is related to formation of the large Irkutsk-Cheremkhovo coal basin. These deposits consist of humus coal and saprolitic bog coal. Among Jurassic sediments, there are also large deposits of fire clay and high quality kaolin which can be used for refractory brick and building materials.

Geologists of East Siberia continue to explore deposits of the Pre-Angara region which is one of the most interesting and richest geological provinces of our country.

WHERE IS 'BIG OIL' TO BE SOUGHT?[1]

by

P. Antropov[2]

• translated by Current Digest of the Soviet Press[3] •

ABSTRACT

In order to meet a planned increase in annual oil-production to 240 million tons and gas to 150 billion cubic meters, oil and gas exploration in the U. S. S. R. must be greatly expanded.

The former Minister of the Oil Industry is criticized for neglecting this phase. Finds and Prospects in Central Asia, Kazakhstan, the northern Pre-Caucasus, Siberia, and the Far East are reviewed. -- M. Russell.

The fuel balance in our country has been undergoing drastic reorganization in recent years as a result of measures taken by the Party Central Committee. The priority extraction and production of such efficient and inexpensive fuels as natural gas and oil will result in huge savings. This policy, based on a thorough study of the country's economic operations and resources, was fully upheld in decisions of the 21st Party Congress.

During the current seven-year period, oil extraction in the U. S. S. R. is scheduled to increase to between 230, 000, 000 and 240, 000, 000 tons and extraction and production of gas, to 150, 000, 000, 000 cubic meters; this will raise the proportion of oil and gas in the total fuel output to 51 percent in 1965, as against 31 percent in 1958.

As is known, we have discovered major new oil and gas deposits, primarily in the European part of the U. S. S. R. between the Urals and the Volga, from Perm Province to the Astrakhan steppe. This has made possible the extablishment of a large oil-and-gas-extraction industry in the Urals-Volga area. Substantial geological discoveries have been made in the Northern Caucasus, the eastern part of the Ukraine, Uzbekistan, Turkmenia, and Azerbaidzhan.

The economy's rapidly growing needs for natural gas and for petroleum products cannot be satisfied, however, solely by increasing the prospected reserves in the oil-and-gas-extracting regions already being exploited in the U. S. S. R. More vigorous geological prospecting and surveying must be carried out in new areas that have been little explored but that hold promise from a geological standpoint, above all in the U. S. S. R. 's eastern regions.

In the past, the former U. S. S. R. Ministry of the Oil Industry made a major mistake in carrying out geological prospecting and surveying for oil and gas by failing to pay due heed to exploration and prospecting in the little-studied regions of the country. The result was that for many years no deposits of any major consequence were discovered in the highly promising regions of Central Asia, Kazakhstan, and the Northern Pre-Caucasus or within the vast reaches of Siberia and the Far East.

It is only in the past few years that surveying work has developed properly in the scantily explored provinces of Uzbekistan and Turkmenia. Already this work has led to discoveries that have placed these regions among the U. S. S. R. 's richest oil-and-gas-bearing areas. The oil-and-gas deposit of Gazli and several others in Bukhara Province whould be considered the most outstanding finds. In the current seven-year plan alone, exploitation of these fields will result in savings of as much as 10, 000, 000, 000 rubles as against the capital that it would have been necessary to invest on construction of new coal mines for extraction of an equivalent amount of fuel.

Discovery of gas-condensate and oil deposits in the Oka-Rem area south of Krasnovodsk also should be regarded as one of the important accomplishments of recent years. Formations favorable for oil and gas accumulation have been traced here over a distance of 80 km. They contain a number of productive strata.

As a result of these discoveries, the extensive territories of the western provinces of Uzbekistan and Turkmenia, as a whole, may be regarded as an extremely rich oil-and-gas-

---

[1]Translated from Pravda, (complete text), Dec. 4, p. 3, 1959 .

[2]U.S.S.R. Minister of Geology and conservation of Mineral Resources.

[3]Reprinted with permission of copyright owner, The Current Digest of the Soviet Press, vol. 11, no. 49, 1960; published at Columbia University by the Joint Committee on Slavic Studies, New York.

bearing region with a potential probably no less than that of some of the richest oil-and-gas countries of the Middle and Near East.

The Tadzhik Republic has extremely bright oil-and-gas prospects. Insignificant low-grade oil deposits once were discovered in tertiary systems in its intermountain depressions. In light of the discoveries in western Uzbekistan and the southeast part of Turkmenia, altogether realistic prospects now have appeared for prospecting and discovery of new oil and gas deposits in deeper-lying Cretaceous and Jurassic formations.

The western regions of Kazakhstan and the Lower Volga area, situated within the vast Caspian depression, are of no less interest. In their geological structure these provinces greatly resemble the very rich Gulf of Mexico depression from which the U. S. A. extracts approximately 45 percent of its oil and more than 60 percent of its gas.

In the past, the volume of geological prospecting for oil and gas in these provinces was slight; and furthermore, it was centered on the limited territory of the southern Emba River region. For many years hardly anything was done to explore the lateral parts of the Caspian depression, the area between the Ural and Volga Rivers, the provinces south and southeast of the salt-dome development zone, and the areas of Ustyurt and Mangyshlak. Yet the prospective reserves of oil and gas (calculated in terms of oil) in the aforementioned provinces of western Kazakhstan and the Lower Volga region are estimated by our scientists in billions of tons!

In view of the imposing tasks confronting the country's oil and gas industry, it is a matter of urgent necessity that the quest for oil and gas be pursued more vigorously over the current seven-year period in the regions of Siberia and the Far East.

There, too, the search for oil and gas has been under way for a number of years now, but owing to fallacies in the orientation of the work the results are manifestly disproportionate to the energy and funds expended. Regional exploration has lagged sharply and formations have been subjected to industrial prospecting without first ascertaining the over-all oil-and-gas-bearing prospects of the explored areas.

Are there grounds for anticipating the discovery of new oil-and-gas-bearing fields in Siberia and the Far East? Absolutely. Historical analysis of geological development of these vast and as yet little explored territories leaves no room for doubt that all the preconditions exist there for discovery of major oil-and-gas-bearing fields.

There are good prospects for discovery of oil and gas in the intraplatform depressions and buried anticlines in the central and northern parts of the vast Western Siberia lowland, the Vilyui and pre-Verkhoyansk depressions of Yakutia; the Khatanga and Ust-Yenisei depressions of the arctic part of Siberia; large territories in the Lena, Angara, and Tunguska River basins in Eastern Siberia; and, finally, the Far Eastern areas of the Zeya-Bureya and Middle Amur depressions.

Discovery of several gas deposits in the vicinity of Berezovo downstream on the Ob River, gas gushers in the Vilyui depression and influxes of gas and oil in the Parfenovo, Osinsk, and other areas of Irkutsk Province, in conjunction with the general geological characteristics of these regions, leaves no doubt that Siberia and the Far East hold enormous resources of gas and oil.

Of great interest is the Northern Pre-Caucasus, where high-yield gas and oil deposits have been found in recent years, particularly in Mesozoic formations that also were very little prospected before. These discoveries place the Northern Pre-Caucasus among the regions that unquestionably have excellent prospects.

The last few years have been marked by discovery of major new oil-and-gas-bearing regions in the Azerbaidzhan Republic (in the southern regions of Kobystan and the Kura depression), thus upsetting the belief that Azerbaidzhan's potentialities have been exhausted.

Prospecting for oil and gas in the Ukraine Republic has led to new discoveries in the Dnieper-Donets depression, where new gas and gas-and-oil deposits have been found in Kharkov and Poltava Provinces. These include the major Glinsk-Rozbyshev oil deposit in the central part of the Dnieper-Donets depression. Gas and oil deposits have been discovered in this region in Devonian, Carboniferous, Permian, Triassic, and Jurassic formations.

Good prospects similarly are being verified over extensive areas of the left-bank Saratov and Stalingrad Volga areas, the southern parts of Kuibyshev Province and the southern and northwestern regions of Bashkiria. In light of the exploratory work of recent years, the possibility is not excluded that industrial oil and gas concentrations will be found in the Upper Volga area and the northeast provinces of the European part of the Russian Republic (the Chuvash Autonomous Republic, Gorky, Kostroma and Kirov Provinces, and the Komi Autonomous Republic); as well as on the territory of Belorussia, Moldavia, and Georgia.

There are, thus, enormous possibilities for discovery of new gas-and-oil-bearing regions, provinces, and areas within the European part of the U. S. S. R. as well as on vast stretches of Central Asia, Kazakhstan, Siberia, and the Far East.

The task is to ensure maximum effect in prospecting and geological survey work, that is, the greatest practical practical results with the smallest outlays.

At present only half of the exploratory wells (on the average for the U. S. S. R.) are yielding positive results, while the rest are, to use the geologists' term, dry. If the number of wells sunk with positive results were increased by only 10 percent, savings to the state would amount to billions of rubles.

The first thing needed to raise effectiveness of the work is to step up geophysical explorations sharply and to improve their methods and the quality of geophysical apparatus. Only if geophysical exploration is expanded and improved on all territories can all types of structures favorable to the accumulation of oil and gas be discovered.

In those of the country's provinces that have been little investigated, study of regional geology must be sharply intensified and the supporting well-sinking expanded.

One of the most compelling tasks is to investigate patterns of formation and distribution of the largest high-yield oil and gas deposits in various geological conditions, and, on that basis, to work out the most effective methods of prospecting and surveying. The discovery and working of large, high-yield deposits will make possible extraction of a greater quantity of oil and gas with a far smaller number of wells and, it follows, considerably smaller outlays of labor and money.

This may be illustrated with several examples. In the U. S. A., more than 5000 oil and gas deposits are being worked, but 48 percent of the total extraction is accounted for by 158 deposits. Other countries are characterized by a similar concentration of reserves. Thus 82 percent of the oil reserves of countries in the capitalist world are concentrated in 236 giant deposits. The greatest concentration is observable in the Near and Middle East countries. In 1957, average daily yield per well in thos countries was about 640, 000 tons; which is 16. 5 times as much as in Venezuela and 362 times as much as in the U. S. A.

It is highly important to discover geological conditions in which giant deposits should be sought, and what the patterns of their formation and distribution are.

A number of the largest fields in the U. S. A. are based on deposits of the lithological and stratigraphical types. Among them, for example, is the great East Texas field, which, since exploitation of it began (that is, since 1930) has yielded almost half a billion tons of oil.

In our oil and gas prospecting, however, it was deposits of the structural type that for a long time attracted primary notice. Obviously, we were too little concerned with prospecting for deposits of the lithological and stratigraphical types, while the discoveries of recent years show that in a number of regions of the Russian platform, the Northern Caucasus, Azerbaidzhan, and the Central Asian republics there are realistic possibilities of uncovering substantial oil and gas resources in these very types of deposits.

The role of the so-called carbonaceous collectors (limestones and dolomites) has been increasing year by year in world practice. Approximately 40 percent of the over-all oil reserves of the capitalist countries are accounted for by carbonaceous collectors.

We too have a favorable outlook for increasing the surveyed reserves of oil and gas by discovering deposits in carbonaceous collectors. The Paleozoic formations of the Russian platform and especially the Mesozoic formations of the Northern Caucasus and the Central Asian republics, are highly promising in this respect.

To increase the efficacy of capital investments in geological surveying and prospecting for oil and gas, a number of measures must be carried out involving simplification and lightening of well structures, extensive introduction of reduced-diameter and small-diameter drilling, and mechanization of labor-consuming drilling processes. First of all, we must increase sharply the output of lighter and transportable drilling rigs that will ensure deep-well drilling with reduced and small diameters, of drilling and casing pipe of suitable sizes, and of small-size turbodrills and electric drills. We are badly in need of improved "stratum testers" with which to prove the wells as they are drilled, prior to the sinking of exploiting shafts.

Implementation of these measures is a matter of paramount importance to the national economy.

STUDY OF THE SEASHORES OF THE CHINESE PEOPLE'S REPUBLIC[1]

by

V. P. Zenkovich

• *prepared by the U.S. Joint Publications Research Service*[2] •

ABSTRACT

The coastline of the Chinese People's Republic, more than 12,000 kilometers long, is becoming increasingly important as an industrial site and as a potential source of raw materials. The author participated in the organization of research on coastal dynamics and morphology in several areas. During investigation of silt deposition in the port of Hsin-kang a collection of data on movement of saturated turbid suspensions under natural conditions, has been obtained for the first time. Other areas under investigation include: Liaotung and Shantung peninsulas, Hang-chou Bay and the Yangtze river mouth, Lei-chou-wan Tao peninsula (Kwangtung province), and Hainan Island. A sea-coast studies laboratory was organized recently in the Oceanographic Institute at Tsingtao; research programs are developing at Peiping University, Shanghai Teacher's Institute, and at Sun Yat-sen University in Canton. Perhaps the most difficult problem encountered was lack of data from previous studies or from hydrological observations. Present studies indicate that the seacoasts composed of silt develop uniquely; evidently their stability is determined by changing equilibrium between deposition of silty material into the ocean from river mouths and the amount of material stirred up and removed from the coastal zone by wave action. A low gradient (1:2,000) is characteristic of the great Chinese plain, the drainage belt, and the shoals. Mountainous coastal areas are of the ria type; fringed by an archipelago of small islands. Along embayed, or incurved, areas of the coastline, sandy material tends to accumulate; heavy-mineral accumulations are to be found in these areas. Additional joint Soviet-Chinese coastal-zone studies are proposed under sponsorship of the Chinese People's Republic Academy of Sciences; a planned study on latitudinal zonality in coastal processes will involve comparison of data for the Pacific Ocean coastline from the Bering Strait to the tropics. - - D. D. Fisher.

The coastline of the Yellow, East Chinese, and South Chinese seas, within the boundaries of the Chinese People's Republic, is over 12,000 kilometers long. Development of the national industry of the Republic requires rapid expansion of studies related to dynamics and morphology of this coastline. These studies are indispensable for reconstructing old ports and building new ones, for erecting hydroelectric plants powered by the tides, for exploiting heavy-mineral deposits on new and ancient beaches, and for setting up new industires in coastal waters (in particular, building basins for settling of salt). Several groups of investigators are occupied with these problems in China.

The author was invited by the Chinese People's Republic Academy of Sciences to help organize work designed to study the coastal zone, and to participate in solving the problem of silting-up of the port of Hsin-kang. During our stay in the Chinese People's Republic (September 1958 -February 1959), we were able to complete several shore expeditions on Liaotung and Shantung peninsulas, in the area of Hangchow Bay and the mouth of the Yangtze River, on Lei-chou-wan Tao Peninsula (Kwangtung Province), and on the island of Hainan. We also became familiar with various types of seacoast structure.

FIGURE 1. Work of the expedition of Liaotung Peninsula

A group of young Chinese scientists took part in all of the expeditions; they were the representatives of various reconnaissance parties. Recently in the Institute of Oceanography of the Chinese People's Republic Academy

[1]Translated from Izucheniye morskikh beregov KNR: Vestnik Akademiya Nauk SSSR, v. 29, no. 9, 1959, p. 76-78.

[2]JPRS 2233-N

of Sciences in Tsingtao, a laboratory was organized for study of the seacoast; geographers Ts'ai Ai-chih, Mao Tse-ch'un, Li Ch'eng-chih, and others at work there, have conducted studies of the coast along the Gulf of Pohai and Shan-tung Peninsula. Similar work is carried on by the Peiping University Chair of Geomorphology, headed by Professor Wang Nai-lang. Hang Mo-k'an, a co-worker in this Chair, is studying beach heavy-mineral concentrates on the shores of Liaotung Peninsula. In Shanghai, the seacoast study is conducted by a group from the Teacher's Institute Geographical Faculty, under the direction of Prof. Ch'eng Ch'ih-yu. Study of the seacoast in the south of China (Kwangtung Province) has been started by the Geographical Faculty of Sun Yat-sen University at Canton.

In regard to the silting up problem of the port of Hsin-kang, study of the silted-up shore is being conducted by a special station in conjunction with the Nanking Hydraulic Engineering Institute. The work performed by this station for many years (Director, Prof. Yang-K'ai) deserves the highest praise. A collection of data concerning movement of saturated turbid suspensions under natural conditions has been obtained for the first time in history. Original methods of study were worked out for these very complicated processes.

Investigation of special questions on morphology of the seacoast is also a subject of study by specialists from other Chinese universities and scientific research organizations.

Studies of the coast under conditions existing in the Chinese People's Republic are hindered greatly by the almost total absence of materials from any previous studies or from hydrological observations. Absence of accurate hydrographic maps is particularly unfortunate. Normally these would be compared with present-day maps in order to learn trends in the process of change in coastlines and sea bottom, for at least the past few dozen years. They would have been used as a basis for noting new data as well.

Study of existing materials shows that silty seacoasts which border on the great Chinese plain develop in a way found nowhere else in the world. Stability of these seacoasts is determined, on the one hand, by the changing equilibrium between silty material which enters the sea from river mouths, and, on the other hand, by the quantity of material stirred up and carried by waves away from the coastal zone. A very small gradient (about 1:2, 000 characterizes the surface of the plain, the drainage belt, and the shoals. Each tide stirs up a large quantity of material, which is partically shifted coastwise, and forms powerful currents; some are a dozen, or even a hundred, kilometers long.

In places where mountains occur along the shore, the seacoast belongs to the "ria" type. It is broken up into a multitude of inlets, sometimes is fringed by an archipelago of small islands, and results from flooding by the sea of an irregular land surface in early stages of the erosive cycle. Under the conditions existing in the Chinese People's Republic, where coastal heights are composed of durable rocks, there is practically no erosion. Nevertheless, in many places where the coastline bends inward, large amounts of sandy material have accumulated. In part, this is the product of coastal-slope erosion, but most, evidently, has been carried up from the sea bottom during post-ice-age eustatic transgression. It is precisely on these sandy sections of the seacoast, particularly extensive heavy-mineral accumulations in the south of Kwangtung Province, that large, are found. To locate them, it is necessary to study carefully the history of the development of the seacoast and its present dynamics.

Coral and mangrove coasts are characteristic of the island of Hainan and of several archipelagos which lie farther to the south. Development of these coasts as well as conditions determining economic-mineral accumulation, are governed by important laws that have not yet been clarified (e. g. formation of bauxite deposits). Study of these laws is of considerable scientific interest not only to geologists of China, but to those of all countries, and, in particular, to Soviet scientists.

FIGURE 2. In one of the fishing ports of Hainan

Successful completion of the work was attributed to a great extent, to the tenacity and tirelessness of the Chinese researchers. For instance, in less than two weeks we succeeded in surveying the seacoast of the island Hainan; as a result, very unusual combintations of detritus and organogenic phases of coastal deposits interesting to students of lithology and paleogeography were discovered. The Directors of the Chinese People's Republic

Academy of Sciences found it desirable to have Chinese and Soviet scientists cooperate in further coastal-zone studies; a number of new joint studies have been planned for the next few years. One of these projects will be the study of latitudinal zonality of coastal processes, observable by comparing data for the entire eastern coastline of the Pacific Ocean, from the Bering Strait to the tropics.

In order to learn the methods of research on seacoasts, three young Chinese researchers are studying at the U. S. S. R. Academy of Sciences Institute of Oceanography and at the Moscow University Geographic Faculty.

SUCCESSES IN GEOLOGY IN CHINA[1]

by

P. N. Kropotkin[2]

• *prepared by the U.S. Joint Publications Research Services* •

ABSTRACT

The status of geology in China is summarized. The number of geologists is now several thousand and many more are in training at newly established universities. A general statement of the structural and stratigraphic components of China relates the principal ore deposits to igneous and tectonic activity. Recent geologic studies of note by Chinese geologists include new geologic mapping, oil and coal investigations, discoveries in paleontology and paleobotany, regional and theoretical studies in tectonics, petrography, geophysics and geochemistry. New discoveries of iron and copper have been made, and increased production of coal, oil, mineral fertilizers, and construction materials accomplished. --M. Russell.

***

In China the development of geology began earlier than the development of other natural sciences, such as chemistry of physics, according to the present understanding of these sciences. Up to the time of the formation of the Chinese People's Republic, a fairly high level already had been reached in stratigraphy, paleontology and, to some extent, in tectonics. Nevertheless, during the 10 years of people's democracy in China, successes made in geological studies are much more evident. In the scope of these studies, the Chinese People's Republic has outdistanced a number of large European countries, and has become one of the world leaders with respect to size of deposits of coal, phosphorites, ferrous, nonferrous, and precious metals, certain rare elements, etc. Already known branches of geological science, as well as new branches (practically unknown in China before) were developed, such as petrography, mineralogy, geochemistry, and the study of location of deposits of ores and of other useful minerals; study of prospecting methods has been enlarged, especially of geophysical methods. In other words, the applied science branches of geology received tremendous impetus; the overall level of geological studies has been raised with respect to methods as well as to scope of study.

The all-China Conference on the Geology of Economic Minerals, in which a group of Soviet scientists took part, was convened in the fall of last year; it showed clearly that a high level of development had been reached.

While before the Liberation there were 200 geologists in China, their number has now grown to several thousand. Young specialists are being trained in three important geological institutes created after the Liberation in Ch'ang-ch'un, Peiping, and Ch'eng-tu; there are outhers undergoing training in the metallurgical institute in the town of Ch'ang-sha, and in the universities of Nanking, Kunming and other cities. The instructors and students in all these educational centers are carrying on a great amount of scientific work. There are geological-scientific societies, and several periodicals and translations of works on geology and geophysics are published. The mass of the population participates in prospecting for useful minerals to a greater extent than in any other country. In some provinces, hundreds of thousands of peasants and workers have taken part in campaigns specially arranged for this purpose. Many courses in elementary geology were set up and prospectors were enrolled from the general population. As a result, in 1958 alone, several dozen valuable mineral locations were discovered by them; among these were large deposits of iron- and copper-bearing ores.

The principal organizations which conduct geological prospecting work in China are the Ministry of Geology, headed by the well-known scientist Li Ssú-kuang, and the Academy of Sciences of the Chinese People's Republic. The organization of the Ministry of Geology includes the All-China Scientific Experimental Geological Institute of Peiping; the regional offices of the Ministry make geological surveys and carry out prospecting and testing of economic minerals in nearly all of the provinces. The structure of the Chinese People's Republic Academy of Sciences includes geological, paleontological, and geophysical institutes. Specialized prospecting in relation to the search for economic minerals is conducted by the Ministries of Petroleum, Metallurgy, etc.

What then is the geological picture of China which has been disclosed by the studies of Chinese scientists?

---

[1]Translated from Uspekhi geologii v Kitaye: Vestnik Akademiya Nauk SSSR, no. 9., 1955, p. 60-64.

[2]Doctor of geological-mineralogical science.

The largest part of China is occupied by the Chinese platform, and by the T'a Ling (Sinkiang Province), Ts'ai-tang, Tibet, and Ala-shan tectonic masses. These are generally considered to be block masses split from the platform, and divided from each other by belts of paleozoic geosynclines. In the geosyncline belts the strata are crumpled, faulted, and have various intrusions. The T'ien Shan, K'un Ling, Ch'i-lien Shan (Nan Shan), and Ch'in Ling mountain chains are composed of such folded geosynclinal zones. In the south of China, more recent Mesozoic and Cenozoic geosynclinal folds extend along the Himalayas and can be found in the Red River basin.

The foundation of the Chinese platform is composed of Precambrian and lower Proterozoic granites, gneisses, and crystalline schists. Throughout the greater part it is covered with a thick cap of sedimentary formations and in some places, with effusives. These sedimentary layers which constitute the platform's cap, are particularly widespread; they been thoroughly studied in the heavily populated eastern half of China, where they are found along with numerous deposits of coal, oil shale, oil, phosphorites, bauxites, and manganese and iron ores. In the lower part of the sedimentary cap, there is a thick complex of non-metamorphic upper Proterozoic Sinian (Reefian) deposits, so named because they were originally identified in China (Richthofen and Grabau). These marine deposits (glacial deposits are also present in some places) were formed approximately 500 to 900 million years ago. In some places, they grade into Paleozoic deposits, and resemble them by the nature of the rocks (limes, schist, etc.); many geologists therefore consider it more correct to include them in the Paleozoic system.

The most complete cross section of the sedimentary cap is to be found in the southern portion of the Chinese platform. Here, besides the Sinian formations, there are marine deposits of Cambrian, Ordovician, Silurian, Devonian, and Carboniferous; continental (coal-bearing), marine and volcanic rocks of the Permian era; marine Triassic; and continental agglomerates which belong to the Jurassic, Cretaceous and Paleocene periods. In the northern portion of the platform there are no Silurian or Devonian deposits. In contrast to the South, the Jurassic, Carboniferous Permian, and Triassic periods are almost exclusively represented by continental deposits.

A peculiarity of the Chinese platform is its dislocation. The dislocations (folds of trunk-like and comb-like appearance, faults, and sometimes overthrusts) are related to the tectonic movements of the Jurassic and Cretaceous periods (the so-called Yen Shan cycle of folding), to those of the lower Tertiary Era, and, in Southern China, they are related also to the movements of the Caledonian Cycle which took place at the end of the Silurian and in the Devonian periods. On other ancient platforms of the earth, such dislocations either do not exist, e.g. on the Russian and the North American platforms, or, are manifest only at their margins (the eastern part of the Siberian platform).

The principal ore deposits of China are found in connection with the intrusion of basic igneous rocks and granites which were intruded into the body of the Chinese platform at the time of the Yen Shan movements. They are connected also with the intrusion of the pre-Sinian foundation of the platform, and with the Paleozoic and geosynclinal folds of the belts that delimit or separate the platform into block masses. This is the location of iron, nickel, chrome, lead, silver, zinc, copper, tin, tungsten, gold, and other metals. Some of these metals have been mined since ancient times, but many have been discovered only in the past few years.

It is well known that the basis of geological research is the geological survey; the latter is based on knowledge of stratigraphy, tectonics, and petrography of mountain formations. On geological maps made before the Liberation, more than half the territory of China was covered with "blank areas." In the 1948-1950 period, geological maps drawn at a scale of 1:1,000,000, were made for the eastern part of China," however, they did not come close to covering all the eastern territory of the country. At the present time, with the exception of Tibet and some mountainous and desert sections, all of China is covered by geological surveys of the same scale and even of larger scale. In the last few years new methods of aerial surveying based on Soviet know-how, were employed in mapping the Nan Ling mountain chain and other regions of China.

Stratigraphic research, the basis of mapping, is carried on energetically, particularly in the coal regions and other areas of Northern China (the provinces of Shansi, Shantung, etc.); in the oil-bearing regions of Western China; in Ordos (Shansi Province); in Szechwan Province; in the lowlands of Sung-liao in the central part of Manchuria; and, in other places. In 1956, the Chinese People's Republic Academy of Sciences published a summary of data on stratigraphy as a book "Stratigraphic Tables of China," and an atlas of paleographical maps. In the field of stratigraphy, studies of Chou Shen-hung, Ssu Shih-cheng, Lu I-hou, and others, must be noted, and, on the subject of the stratigraphy of Sinian deposits, the works of Chao Tsun-p'u, Wang Hung-cheng, Hse Chia-wei, and others deserves mention. Many works which are of great interest to Soviet geologists have been prepared for publication in the Russian language.

The work of Sun Yun-cho on trilobites and other invertebrates of the Paleozoic Era; of Yang Chung-chien on the paleobotany of the Mesozoic and Paleozoic deposits; the discovery by Pei Wen-chung, in 1929, of the remains of the Sinanthropus in the caverns of Ch'ou-k'ou-tien to the south of Peiping; and other works completed before the Liberation laid the foundation for the vast series of paleontological and paleobotanical studies being conducted on a wide front in the Institute of Paleontology of the Chinese People's Republic Academy of Sciences and in other Chinese scientific institutions. Soviet paleontologists (A. G. Vologdin and a number of specialists in micropaleontology) have rendered substantial assistance to their Chinese colleagues in the development of up-to-date paleontological and stratigraphical studies. Recently, in the Soviet Union, determination of the absolute age of Precambrian deposits of China was performed for the first time (A. I. Tugarinov and others). Similar studies, as well as work on the spore-pollen and other new methods of stratigraphical analysis, are being organized in the Chinese People's Republic with the help of Soviet scientists; the latter group is composed principally of members of the USSR Academy of Sciences.

A new event in stratigraphy was the discovery of paleontologically-graded deposits of all systems: from the Cambrian to, and including, the Cretaceous in the region of the Ch'i-lien Shan mountain chain; from Silurian to Triassic in the Ch'in Ling mountains; and from Cambrian to Permian in the K'un Ling mountain chain. In addition, marine Devonian and upper-Triassic deposits were discovered in northeastern Manchuria. In Tibet, a geologic section similar to the section in the southern part of the Chinese platform, was discovered along the new Tsinghai-Tibet Road. All of the systems there, from the Devonian to Paleocene, have been characterized paleontologically. To the south of the Tsangpo (Brahmaputra) river, a flysch layer of the upper Paleozoic, Mesozoic, and lower Tertiary eras belonging to the Himalayan syncline was discovered. Some of these new interesting data were found by Chinese and others in the western regions of the country, that had been for so long a blank.

The tectonics of China were elucidated for the first time in the geological outline work of Li Ssu-kuang, published in English in 1939, and in Russian, with supplements, in 1952. In 1945 Huang Ti-ch'in published "The Basic Features of the Tectonic Structure of China"; in 1952, it was published also in Russian translation. Chang Wen-yu (Geological Institute of the Chinese People's Republic) then worked out a special tectonic map of China which was published in 1957, and now has been republished together with the book "Tectonics of China." This book uses the methods of studying the history of tectonic structures by phase and formation of the deposits found in them (so-called formation analysis) and by their thickness (so-called isopachous method). These methods were perfected in the Soviet Union by N. S. Shatsky, V. V. Beloussov and others.

Under the leadership of Chang Wen-yu, Chinese geologists together with Soviet scientists are engaged in the major collective project of compiling a tectonic map of Eurasia. Tectonics are used in China as the basis for predictions required in the search for economic minerals. Much attention is given to the peculiar dislocations of the Chinese platform, which make it possible to classify it as a special type of "activated platform." In addition to the tectonic scientists mentioned above, this matter is being studied by Cheng Kuo-ta in Ch'ang-sha, and by other geologists. The theory of the preponderant importance of horizontal movements, for the study of dislocations caused by shifting, paleomagnetism, etc., has long been under study by Li Ssu-kuang; he has used it for illustrating his ideas in experimental tectonics. It is gaining wider and wider acceptance in the West and in the U.S.S.R.

Petrotectonics, or the microscopic study of formations which occur in volcanic and other rocks as a result of tectonic deformations, is described successfully in the works of He Tso-ling.

At the suggestion of N. I. Nikolayev, E. F. Savarensky, and other Soviet scientists, neo-tectonic research has been started in China. Interesting results in the evaluation of the seismic grade of the different regions of China were obtained by selection of data noted in ancient Chinese manuscripts over a period of 2,000 years.

Studies in petrography of volcanic rocks, in lithology, in mineralogy and geochemistry began to be developed in China only in the past 5 or 10 years. This is particularly true of geochemistry which was practically nonexistent until recently; in connection with the study of ore deposits and the search for rare and scattered elements, its development has received great forward impetus. In addition, one should cite the works of Chinese geologists on the geochemistry and mineralogy of basic and ultra-basic rocks, and on the deposits of chromium, nickel, etc., found in connection with these rocks (Li P'u); on the lithology, mineralogy and geochemistry of manganese formations (Yeh Liang-chun); on the metal-producing capacity of endogenous deposits related to granitoids (Meng Hsien-min); and others. The experience of Soviet geochemistry, based on the works of A. E. Fersman and V. I. Vernadsky, the founders of this science, is used widely at present by Chinese scientists.

The geophysical studies conducted by the Geophysical Institute of the Chinese People's Republic Academy of Sciences and special teams of the Ministry of Geology and Petroleum, are progressing more and more every year. Among those are, first of all, the aeromagnetic and surface-magnetic surveys in Manchuria and in the lower course of the Yangtze, conducted in connection with the search for iron ores and for clarification of the general structure; gravimetric and other studies in the oil-bearing regions; etc. At the recommendation of the author, studies were begun in China of paleomagnetism for stratigraphic correlation of deposits; and, in order to discover laws in the field of tectonics and paleoclimatology.

Socialist construction in China is making ever-increasing demands on geology; this guarantees its even faster growth in the years to come. In 1958, China overtook England in coal mining and soon will overtake her in the production of iron and steel. Growth in the production of nonferrous metallurgy, oil production, mineral fertilizers, and construction materials is particularly rapid.

These splendid results, most of them achieved in a very short period of time (the last five or six years), show that the sciences and the productive forces of a country develop at a great rate of speed once the people have thrown off the chains of exploitation and have become the masters of their own country.

Review Section

GEOPHYSICAL PROSPECTING IN COMMUNIST CHINA. Extracts of a translation of THE RESULTS AND FUTURE OF SCIENTIFIC RESEARCH IN GEOPHYSICAL PROSPECTING IN COMMUNIST CHINA, by Chou Chin-han, Assistant Director, Institute of Geophysical Prospecting and Research, Ministry of Geology: Ti-ch'iu Wu'li K'an-t'an [Geophysical Prospecting] no. 9, 22 September 1959, p. 8-12, Peiping. Translation by U. S. Joint Publications Research Service, JPRS: 1119-D, OTS: 60-31, 023.

Geophysical and geochemical prospecting methods are powerful tools for general geologic survey and exploration. Recent experience has proven that geophysical and geochemical methods can increase the rate of progress, improve quality and reduce costs in geological work. These methods are numerous, fast, reliable, and time and money saving.

In the ten years of the rebuilding of the country, the field of geophysical and geochemical prospecting has enjoyed tremendous expansion and development and achieved great success. Before liberation, only a few were engaged in experiments of some of the methods. Starting with the use of magnetic methods for locating magnetic ore bodies, there was quickly developed the use of combined methods for the search of numerous other varieties of ore. During the First Five-Year Plan, geophysical and geochemical work adopted the policy of "reinforcement while carrying out experiments and production" to develop geophysical and geochemical methods as demanded by geological work. With the assistance of the Soviet experts, our geophysicists and geochemists have, within a short period of time, mastered many geophysical and geochemical prospecting methods. Furthermore, we have by imitation constructed an EP-1 type potentiometer.

During the rapid increase of production, numerous problems were discovered which required immediate solution by scientific research. In 1956, the party and the government emphasized the importance of science to military power and established a 12-year plan of scientific research. It was requested that all those institutes concerned should quickly establish an organization for development of research of geophysical and geochemical prospecting. Besides the applied geophysical section of the institute of geophysics of the Academia Sinica established shortly after liberation, the Ministry of Geology established an institute of geophysical prospecting in 1957. Since then the Ministry of Petroleum Industry, the Ministry of Metallurgical Industry, the Ministry of Coal Industry, etc., have sections undertaking the research of geophysical prospecting. Since the existence of these research units, their first job was to help the various production organizations to master those geophysical and geochemical methods in practice in foreign countries. At the same time there was started the task of regular research. At present, production departments are using the majority of the well-tested geophysical and geochemical methods introduced from foreign countries. Most of these methods and wo rking experience were learned from Russia. Others were from the experience in Hungary and Poland. In general, the production teams have mastered individual methods of geophysical and geochemical prospecting; however, in many aspects they lack logical and effective methods that can successfully solve various geological problems, and urgently await solution from research. Some new results of foreign research, especially those new recent scientific results of Soviet Russia on geophysical and geochemical prospecting, bear great practical significance for the development of our geological work which we should at once master and study.

In 1958, the scientific personnel of geophysical and geochemical prospecting departments put science under the rein of duty and have set the direction of research. Hence, the science and research of geophysical and geochemical prospecting made great progress alongside the country's industry and agriculture.

Emphasis was on the geophysical prospecting of metal. Research in geophysical and geochemical prospecting of the past two or three years was carried out by the bureaus charged with such duties and by the universities and technical institutes. This program will be explained under the following three headings.

1. The Mastery and Study of New Methods.

Since the geophysical teams have learned the various proven methods of geophysical prospecting, the research effort of methods and development is concentrated on:

(1) The Study of Geophysical Methods Concerned with Disseminated Ore Deposits

Since most of the country's colored metal deposits, particularly that of copper, are largely of the disseminated type, the search for such deposits has been of particular significance with the adoption of the policy of cooperative development of industry by the central and local government. The main methods for locating such deposits are by the use of an excitation potentiometer and an induction method.

The excitation potential method: In testing some of the massive or disseminated types of copper, lead and zinc deposits, there was a clear η anomaly. In many cases the η peak corresponds to the trough of ρ_k. In some of the copper, lead, and zinc polymetallic deposits of Kansu Province, under similar ground water and geological conditions and at similar depths, the η anomaly of high grade disseminated ore bodies is more pronounced that those of the massive type. When other methods using direct current are ineffective in detecting medium grade disseminated ore bodies, the η anomaly is quite evident. This method was shown to be effective since it located new ore bodies when tested near a known ore body. Its present prospecting depth is 40-50 meters. Preliminary results show that this excitation potential method, where depths are also determined by the same method, is capable of determining whether the η anomaly is due to ore bodies at shallow or great depths. It also shows that the method was capable of distinguishing electrical conductors from ionic conductors which serves to differentiate anomaly due to ore or gangue. This research not only solves the problem of locating disseminated metallic ore bodies, but also detects the large electrical anomaly in the area of production and the type of anomaly which is of great significance. The method has received the general confidence and attention by the production personnel. The excitation potential method is a method of great promise.

The induction method: Tests on copper and nickel deposits of our country show that this method is more effective in locating buried massive ore bodies or discontinuous veins at shallow depths than other methods using direct current. This method still has short-comings, and because of this it cannot be used without restrictions. The method however will become a major tool in electrical prospecting of the dry regions of the northwest and the high mountainous regions and the permanently frozen region of the north. Since the great advance the geophysical teams of many provinces would continue working during the winter, thus the inductive method becomes more important. From the experimental results this method is superior when used in mapping. For example, in the fractured contact zone of different rock formations, the rocks showing low resistivity also show clear anomaly.

(2) The Study of Geophysical Methods for Well-logging

In the past, the main geophysical methods for well-logging were the electrical resistivity and the natural electrical field method. Although these methods get a certain response when applied to oil and coal fields and metallic deposits, there are other more effective methods in the foreign countries which can be used for such geological prospecting and exploration work. The combined use of well-logging methods in exploration and serve as a powerful tool in the partial or complete non-core sampling type of drilling of holes in the coal field or metallic deposits.

Gamma well-logging method (GK): This method has shown its extremely superior performance in the search for uranium ores and for estimating the reserves of uranium ore. Past experience has shown that this method is effectively used in correlation of stratigraphy and for logging geologic sections in oil field coal and metallic deposits. Where employed in mining districts of northern parts of China, the method shows the following characteristics: (a) The shape of the curves shows little change in space. Usually where there is a consistent key bed, for example in a certain lead zinc district, the record of three drill holes reaching the contact of a banded limestone and brecciated limestone shows three peaks: Based on this regularity, the key bed can be located in a well or with respect to an ore body. (b) Well casting and the diameter of the well show little effect on the curves. It is also of significance in the general detection of radioactive mineral which may be encountered in a coal field or in metallic deposits. In a certain area of experimentation, an abnormally strong radioactivity was thus detected. The GK method is indispensable as a part of the combined method.

Gamma-gamma well-logging method (GGK): In a certain area in Hopeh Province where the experiment was carried out, the specific gravity of the coal and its country rock has a difference of 0.9-1.5 gm/cm^3. In general, coal seams more than 0.2 meters thick show positive anomaly. This method can solve some of the problems not solved by electrical methods, such as the differentiation of coal and rocks with high electrical resistivity. Results of the experiment show clearly that surveyed curves successfully differentiate the coal bed and its capping limestone, the former shows a high peak in contrast with the latter, a low peak. Moreover, good results are also obtained in separating anthracite

from rocks of low resistivity. The experiment also noted that the various diameters of the well give false anomalies of different amplitude, so that with the sole use of this method, one would not be able to identify the type of anomaly. Tests of this method on metallic deposits also show that GGK is a major part of the combined method for well-logging.

Neutron-gamma well-logging method (NGK): This is an effective method in the determination of the porosity of strata in oil fields. Recent test drilling of boron-bearing ground shows a clear anomaly, thus the same method can probably also be used in the study of the variation of boron content. In the study of coal fields, the NGK method is used to demarcate the stratigraphic position of limestone from dense sandstone by a clear high peak, and in wells drilled in carbonates, it can detect the clayey portion and the water content of clayey beds, and thus the position of the clay beds can be located.

Electrode-potential method (MEP): Test on a certain lead-zinc deposit of Liaoning Province shows that this method can demarcate the conductor-metal ore body if the ore body is a good conductor or if it is massive or fairly well concentrated. The MEP method plays an important part in determining the location and thickness of the ore body penetrated by drill holes. It is a major method of the combined drill hole surveying scheme with regard to metallic ore deposits. Under general conditions the battery dipole (MPGP) also has the MEP function. Test results show that under favorable conditions, it is possible for the MPGP method to estimate the mineral composition of the sulfide ore.

Electrolysis method of well-logging (EK): The method can determine the location of a metallic ore body; primarily it determines the position of the disseminated type of ore body. The excitation potential method is improved as a result of experiments done on the EK method. It was discovered that under difficult conditions, the excitation potential method of well-logging gives a surprisingly satisfactory result.

(3) The Study of Highly Efficient General Geochemical Prospecting Methods and Geochemical Methods for the Locating of Hidden Ore Bodies

In the past, general geochemical survey methods were used to locate secondary halos. Now other countries have discovered a highly efficient general survey method -- the drainage and water analysis. It employs a small sample quantity and delineates the general area of the ore. This will have a serious effect on the search of possible ore reserves of various areas. This method can be easily mastered and geologists can use it as a personal ore-prospecting tool. The work of locating hidden ore bodies by locating primary halos and water analysis has become a daily routine.

Primary halos: It is used to locate hidden ore bodies, locate mineralized areas and study the characteristics of ore formations. In a certain place in Kweichow Province, where bedded type and fissure filling type of mercury deposits occur, this method, which determines the mercury anomaly, can locate and delineate the mineralized area by sampling along faults. The trace of mercury in rock samples was first determined by highly sensitive spectrographic analysis to establish by contrast, a clear anomaly, with samples taken above known mercury ore bodies. Tests show that in areas where foliation or sheeting structure prevail, the condition favors the formation of primary halos over hydrothermal metallic deposits of copper, lead, and zinc. The halo disperses for distances of about 150 meters. Analyses of drill cores show that the primary halo was originated along the foliation of the country rock. Cores located above the ore body show the same anomalies as those of the surface sample lying along the same plane of foliation. Large amounts of test data indicate that this method has a great future and shows great promise for discovering hidden ore bodies.

The water analysis method: The chemical analysis of water shows good results in areas where springs are abundant. Since the metal content in the surface water is lower than those in the sediments at the river bottoms, the anomaly obtained is rather weak, therefore the method is generally supplemented by the drainage sampling method. Using ΣM (Pb + Zn + Cu) with Pb and Zn as the principal indicator and using SO_4^{2-} and SO_4^{2-}/Cl^- ratio as the secondary indicator, in the Nan-ling region, every mineralized district reflects such variations. Based on the intensity of the anomalies and the type of ore indicator, the various types and degree of mineralization are indicated. This method, useful in locating hidden ore bodies, is not only highly effective but the analysis of spring water also indicates its sources from a greater depth.

Biogeochemical methods: This type of experiment is still in its infant stage in China. The Mai-chou hsiang-hsu plant [Elsholtria patrini oarcke] is a copper indicator discovered in Anhwei Province. Later in Szechwan Province another copper indicator plant, the Maliaotzu [Polygonum posumbu] was discovered.

Field and laboratory methods of rapid analysis: Within the last few years, field color comparison methods of analyzing Cu, Ni, W, Cr, As, Mo, and sulfate were established; rapid spectral analytical methods were established for Ag, Hg, Nb, and Be; and direct determination of the total heavy elements in water solution for Pb, Cu, and Mo, and the total precipitation or

settling of several of the heavy metallic ions. These are the prerequisites for productive field work and laboratory studies.

2. The Copying and Trial Manufacture of Instruments for Geophysical Prospecting

In the past, instruments for geophysical prospecting used by the production teams were largely imported from foreign countries. Because of our vast country and the numerous areas where geophysical work is to be done, the demand for equipment is rather great and we cannot rely only upon imports. We must increase the trial manufacture or manufacture by imitation to satisfy the demand of geophysical prospecting of every research unit where certain personnel are assigned to do this type of work. The simultaneous execution of research and production have greatly increased the speed of trial manufacture or manufacture by imitation. At present, there are more than ten kinds of instruments in use for production work which are made in this manner.

Success in the trial manufacture of such instruments not only saved a good deal of foreign exchange but also, in the process of trial manufacture, we have trained personnel, raised the standard of making instruments and established a firm foundation for instrument research. At the same time, we also partly satisfied the demand of equipment for geophysical prospecting. On the basis of this type of work, we have succeeded in making the following instruments for geophysical and geochemical prospecting:

Aeromagnetometer type 402: Installed on An-2 airplane, it is capable of surveying the magnetic field and the field of natural radiation. The weight of the instrument installed in the airplane is 130 kg. The sensitivity of the instrument is 10 gamma/mm and its precision is 30 gamma ±.

Semiconductor-magnetometer: The characteristics of this instrument is its small size, light weight and low cost of manufacture. The survey instrument is made of magnetic elements of high conductivity. Its sensitivity approaches 50 gamma/gm. The alternating current-power supply consists of an oscillator made of semiconductors and an amplifier. The output rating is 0.1 watt, 15 milliamperes. It can be used to find iron ore or to distinguish strongly magnetic rocks and minerals. This instrument not only makes spot surveys but also continuous traverses.

Magnetic well survey instrument: This utilizes the phenomenon of magnetic saturation of P'o-mo [probably alnico] alloy to detect the variation of the vertical magnetic field of a drill hole. At present because the mechanical part of the sensitive instrument which was to be suspended in the well was not precisely made, its sensitivity is but 200 gamma/mm. The instrument is able to distinguish magnetic from non-magnetic minerals or to locate a hidden magnetic ore body that has been penetrated by drilling.

Trench radar-type instrument: It consists of signal sending part and a receiving part. The signal sending part uses a whip-shaped antenna with an output of 4 watts. Its operating frequency is 3,750 kilocycles. The receiver is of the superhetrodyne type and can receive directional signals. The instrument can be used to locate hidden ore left undetected near a known ore body.

Excitation-potentiometer: It consists in part of a 5,000-watt direct current generator mounted on a small automobile. The survey employs an automatic electronic compensator and records the value directly by a pen. It can record four sets of electrical potential differences simultaneously.

Field counters: It is a highly sensitive scitillometer type of radiation counter which counts radiation. The instrument has three steps (I: 0-50 milliroentgens/hour, II: 0-150 (probably should be some other figure than 0, such as 100-150) milliroentgens/hour, III. 700-800 milliroentgens/hour). The sensitivity using a radium source is: 180-200 pulse-minute for every milliroentgens per hour.

Scintillometer well-surveying instrument 203 type: It is a well-surveying instrument consisting of a scintillometer with preamplifier, rectifier, cathode output, and high voltage power supply. The high voltage power source stability consists of direct current from 210-milliampere reduced to 0.15 percent. Current consumption is 210-240 milliamperes. Survey error: current remains constant for a period of 8 hours not exceeding 8.5 percent. This instrument has the following advantages over the PARK well-surveying instrument: higher sensitivity, more power in distinguishing strata and is easier to raise or lower into the well. It is suitable for use in oil or gas fields, in coal fields, and metallic mining areas employing GK. GGK, and NGK types of surveying instruments.

Neutron-neutron well-surveying instrument: The instrument uses a neutron counter of the GM-4-5 type. The output pulses of recording type is around 0.4 millivolt preceded by a 150,000-times amplifier. The high voltage was set for 1,350 volts. The power supply voltage is 200 volts and the current is 210 milliamperes. The instrument is used in the determination of the porosity of the rocks and in locating the water-oil boundary.

Elastic wave meter: This surveying instrument is based on a revised and simplified circuit of

of a supersonic (frequency) seismogram. It consists of a frequency generator, a transducer, a receiver-oscilloscope, etc. The instrument is used by seismic field parties for determining the elastic coefficient of rock. It can determine such properties of any rock specimen with two nearly parallel surfaces.

Gaseous color titration equipment: The sensitivity of the equipment is 6×10^{-4} percent, precision 20 percent. It can analyze a sample in 50 minutes. This analytical instrument is a preliminary contribution.

3. The Application of the Combined Use of Geophysical and Geochemical Prospecting Methods to the Work of Geological Surveying

General survey of metallic ore deposits: Large amounts of field data on geophysical and geochemical prospecting were accumulated during many years of production. By actual experience, the geophysical and geochemical prospecting of important deposits of iron, copper, lead-zinc, chromium and nickel were accomplished.

As shown by actual results, the various types of iron, copper and lead-zinc deposits have been classified according to their geologic occurrence and methods of geophysical prospecting of such deposits. In addition, the application of geophysical and geochemical methods and the types of problems that can be solved by them concerning chromium and tungsten deposits have been understood. These are of great importance to the development of large scale geophysical prospecting of ore deposits in the future.

Hydro-geological and engineering geological surveys: Under the leadership of Polish experts the type of mineral spring and the location of hot springs of a certain region were surveyed by electrical methods. The thickness of the porous sediments were determined and quifers were located. The electrical method was also successful to some extent in locating areas where karst was developed.

Geophysical prospecting in wells: The combined use of GK and GGK methods in logging wells of coal fields provided sketchy geological maps, marking out the contacts of the coal seams and determining the depths and thickness of thin coal seams. Where the quality of the coal is known and the geological structure was simple, general survey by drilling can be carried out without obtaining core samples locally and in areas where detailed surveys were carried out, drilling can be done without core recovery. The combined use of MSK, MEP and GGK well-logging methods in the study of iron, copper, lead-zinc, and other metallic deposits can determine the depths and thickness of the ore bed to supplement data from an inadequate number of drill holes. A quality control chart guides the sample splitting and analyses and classification of the mineral composition of ores, thus differentiating low grade from high grade ore, and allowing drilling to proceed locally without recovering drill cores.

[Under the heading "Responsibility of Scientific Research", the remainder of the article deals with a review of methods the author urges accelerated development in China. Subjects included are: seismic methods, gravimetric methods, magnetic methods, electrical methods, radioactive methods, well-surveying methods, geochemical methods, water analysis methods, biogeochemical methods, offshore prospecting, compilation of a handbook "of major regions for workers in geophysical and geochemical prospecting," development of more portable geophysical prospecting instruments.]